chapter

5 Evolution

In this chapter

- Exploration: Curiosity Generates Questions
- Chemistry Connection: Classifying Chemicals
- Mini Investigation: Classifying Organisms
- Investigation 5.1: Using a Classification Key
- Mini Investigation: Puzzling over Evidence
- Web Activity: Finding Fossils and Famous Footprints
- Mini Investigation: Variations on a Theme
- Lab Exercise 5.A Evidence from Genetics
- Web Activity: Were Neanderthals Humans?
- Mini Investigation: Genetic Shuffle
- Investigation 5.2: Measuring Inherited Variation
- Web Activity: Lactose Intolerance and Evolution
- Web Activity: Natural Selection

Black widow spider females (**Figure 1**) often consume their partners during mating. How can such unusual behaviour be explained? To answer this question, biologists have to understand and apply of the theory of evolution.

Researcher Dr. Maydianne Andrade believes she has found the answer. Some male black widow spiders intentionally offer their abdomens as food to the females. The females normally mate with several males, store their sperm, and use it to fertilize as many as 3000 eggs. Males who do not sacrifice themselves rarely mate with more than one female. Males who volunteer their bodies as food during mating extend their mating time and transfer more sperm to the female, increasing their chances of fertilizing eggs. Thus, males who are eaten have more offspring than those who are not. These findings support the conclusion that the volunteering-for-cannibalism behaviour has evolved because it increases the reproductive success of males who perform such behaviour.

Evolution is a compelling scientific theory that explains not only how organisms change over time, but also the diversity of species. To appreciate and judge the significance and validity of this theory, it is important to examine the evidence and to review the nature of science as a way of gaining knowledge. As you will learn, evolutionary biology is a modern science that provides answers about the past and has present-day applications in many fields of study, from medicine to conservation biology.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Domesticated animals such as dogs, cats, horses, and cattle are descended from wild animals. Why do many different domesticated breeds now exist? How could breeders have produced animals with traits that their wild ancestors did not have?
2. Penguins, ostriches, and eagles share many similar features, while fish, antelopes, and bats do not. Offer an explanation for such findings.
3. Why are some bacteria becoming immune to antibiotics?
4. The vast majority of fossil species are no longer alive today, and many species that are alive today are not found as fossils. Why?

Career Connections: Paleontologist; Breeder



Figure 1
A male of the black widow spider increases his reproductive success when he allows the female, shown here, to consume his body during mating.

Exploration — Curiosity Generates Questions

Most humans are curious by nature, and scientists particularly so. Whenever someone witnesses an unusual event or discovers an unusual object, questions immediately arise. What caused the event? Where did the object originate? When we try to answer such questions, we start with the knowledge and beliefs we already have.

Carefully examine the puzzling images in **Figure 2**.

(a) Generate two questions about each image.
(b) Based on background knowledge and understanding you already have, write short answers to your own questions.
(c) Exchange your question set with a fellow student. Record and respond to his or her questions.
(d) Was it difficult to generate questions about the images in **Figure 2**?
(e) Was it difficult to answer the questions? How confident do you feel about the accuracy of your answers?
(f) What specific steps would you take to better answer these questions?
(g) Would you describe your approach as a "scientific method?" Why?

(a)


(b)


(c)


(d)


Figure 2

5.1 Classification of Organisms

CHEMISTRY CONNECTION

Classifying Chemicals

Classification also plays an important role in chemistry. For example, scientists can predict the behaviour of elements in chemical reactions based on their position in the Periodic Table. Your chemistry textbook has more information on the use of classification in chemistry.

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Scientists estimate that there are at least 10 million different species alive today. However, this number is only a small part of the hundreds of millions of species that have existed on Earth over time. Understanding the dramatic history of Earth's changing biological diversity is the goal of evolutionary biology. Before studying how populations change over time (evolve), it is useful to understand Earth's current biological diversity. Biological diversity is usually a sign of a healthy ecosystem. When an ecosystem is biologically diverse, there is a higher chance that some organisms will survive changes in the ecosystem that arise.

There are two levels of biological diversity: (1) species diversity, which describes the number of different species; and (2) genetic diversity, which refers to the amount of variation in inherited traits between individuals of the same species. In this section, you will consider species diversity, by looking at how scientists use a classification system to understand the similarities and differences between species.

mini Investigation Classifying Organisms

It is not always easy to classify an organism. To decide, a scientist makes careful observations. Clues are compiled based on organizing similarities and differences. Eventually, the clues can be linked and a conclusion can be drawn. Scientists then look for ways of testing their conclusions.

Examine the organisms in **Figures 1** to **6**.

(a) Speculate about which organisms are plants and which are animals. Give your reasons. *Hint:* recall the cellular differences between plants and animals.

(b) What test would you conduct on each of these organisms to determine whether they are plants, animals, or something else?

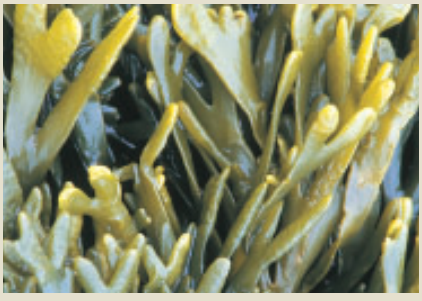


Figure 1
Fucus, a seaweed



Figure 2
Sponge

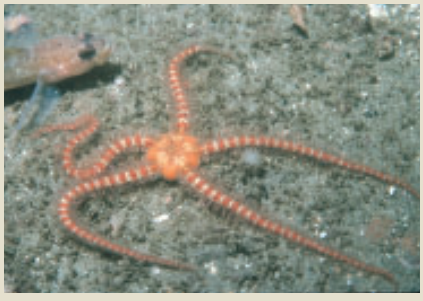


Figure 3
Brittle star



Figure 4
Coralina, a red alga



Figure 5
Sea anemone



Figure 6
Coral

Taxonomic Systems

Estimates of the number of living plant and animal species range somewhere between 2 and 4.5 million. Bacteria and other microorganisms add several more million species to this total. Many scientists believe that there may be up to four times this number, including many species that are now extinct. Is it any wonder, given the numbers and diversity of living things on this planet, that classification is a major field of biology? The science of classifying organisms is called **taxonomy**. Scientists who carry out this work are called *taxonomists*.

taxonomy the science of classification according to the inferred (presumed) relationships among organisms

Biological classification systems have two main purposes: identifying organisms and providing a basis for recognizing natural groupings of living things. However, classification systems are artificial. They are developed by scientists to help deal with the diversity of life and to represent relationships among organisms.

Our present biological system of classification was developed from the system created by Swedish botanist Carl Linnaeus (1707–1778). His system was based on an organism's physical and structural features, and operated on the idea that the more features organisms have in common, the closer their relationship.

Linnaeus created rules for assigning names to plants and animals. He was the first to use **binomial nomenclature**, which assigns each organism a two-part scientific name using Latin words. Latin (and sometimes Greek) is still used today for naming organisms, and provides a common language for all scientists. A scientific name is often based on some characteristic such as colour or habitat; an example is *Castor canadensis* (*Castor* meaning "beaver," and *canadensis* meaning "from Canada"). The first part of any scientific name is called the **genus** (plural: genera). Its first letter is always capitalized and can be written alone; for example, the *Acer* genus refers to maple trees. The second part is called the **species** and is never used alone; for example, *Acer rubrum* refers to the red maple. Living organisms within a species can usually only breed with members of their own species to produce fertile offspring.

binomial nomenclature a method of naming organisms by using two names—the genus name and the species name. Scientific names are italicized.

genus the first part of a binomial name; a genus includes several species

species a group of organisms that look alike and can interbreed under natural conditions to produce fertile offspring

The two-name system provides an added advantage by indicating similarities in anatomy, embryology, and evolutionary ancestry. For example, binomial nomenclature suggests that the North American black bear (*Ursus americanus*) and the grizzly bear (*Ursus horribilis*) are closely related. Similar organisms are grouped into the same genus. The giant Alaskan brown bear (*Ursus arctos*) and the polar bear (*Ursus maritimus*) are other relatives belonging to the same genus. By contrast, the koala bear and the panda do not belong to the genus *Ursus* and are not considered true bears.

In our present classification system, there are seven main levels or **taxa** (singular: taxon), as shown in **Table 1**.

taxa categories used to classify organisms

Table 1 Levels of Classification

Levels of classification	Dandelion	Housefly	Human
kingdom	Plantae	Animalia	Animalia
phylum	Tracheophyta	Arthropoda	Chordata
class	Angiospermae	Insecta	Mammalia
order	Asterates	Diptera	Primates
family	Compositae	Muscidae	Hominidae
genus	*Taraxacum*	*Musca*	*Homo*
species	*officinale*	*domestica*	*sapiens*

EXTENSION

Comparing Plants and Animals at the Cellular Level

Listen to a comparison of the structural and functional characteristics of plants and animals at the level of their cells.

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Protista a kingdom originally proposed for all unicellular organisms such as the amoeba. More recently, multicellular algae have been added to the kingdom.

Monera in a five-kingdom system, a kingdom that includes organisms that lack a true nucleus

Originally, the first level consisted of only two kingdoms: plants and animals. Later, single-celled organisms that displayed both plant and animal traits were discovered. To recognize this unique group, scientists created a third kingdom: **Protista**. However, shortly after the introduction of the protist kingdom, it was noted that certain microorganisms within this group shared an additional distinct feature. Bacteria and cyanobacteria, unlike protists, lack a true nucleus. This distinction resulted in the establishment of a fourth kingdom: **Monera**. The monerans are referred to as prokaryotes since the cells lack a true nucleus. All other groups of living organisms are known as eukaryotes. Later, taxonomists acknowledged that mushrooms and moulds are sufficiently different from plants and thus placed them in a separate kingdom called Fungi. This five-kingdom classification system, which includes Animalia, Plantae, Fungi, Protista, and Monera, was originally proposed by Robert Whittaker in 1969. It enjoyed wide acceptance until recently.

Archaebacteria in a six-kingdom system, a kingdom consisting of prokaryotic microorganisms distinct from eubacteria that possess a cell wall not containing peptidoglycan and that live in harsh environments such as salt lakes and thermal vents

Eubacteria in a six-kingdom system, a kingdom consisting of prokaryotic microorganisms that possess a peptidoglycan cell wall

In the 1970s, microbiologist Carl Woese and other researchers at the University of Illinois conducted studies indicating that a group of prokaryotic microorganisms called **Archaebacteria** are sufficiently distinct from bacteria and other monerans that they constitute their own kingdom. Archaebacteria have been known for a long time. They thrive in harsh habitats such as salt lakes, hot springs, and the stomach chambers of cattle and other ruminants. Archaebacteria possess cell walls and ribosome components that are very different from those in **Eubacteria**. Eubacteria are prokaryotes that possess a rigid cell wall composed of peptidoglycan, a three-dimensional polymer containing carbohydrate and protein subunits. Thus, Woese and his colleagues proposed that the kingdom Monera be divided into two kingdoms, Archaebacteria and Eubacteria (true bacteria). The resulting six-kingdom system includes Animalia, Plantae, Fungi, Protista, Eubacteria, and Archaebacteria. **Table 2** on the next page summarizes a six-kingdom system of classification.

DNA sequencing studies conducted by Carol Bult and Carl Woese in 1996 revealed that some of the genes in archaebacteria are more closely related to the genes of humans and other eukaryotes than to those of eubacteria. Woese proposed that archaebacteria are so different from other prokaryotes that their name should not contain the term bacteria. He suggested the name *Archaea* for this group. While the six-kingdom system grows in popularity among biologists in general, many microbiologists feel that all traditional kingdom systems should be replaced with a system that better reflects the evolutionary history of life. This has led to a three-domain classification system (**Figure 7**). Scientists continue to update evolutionary history and classification schemes as more DNA evidence is collected and analyzed.

DID YOU KNOW ?

Most Highly Evolved

Many scientists point out that humans may not be the most highly evolved creatures on the planet. The placement of humans at the top of the ladder is highly subjective.

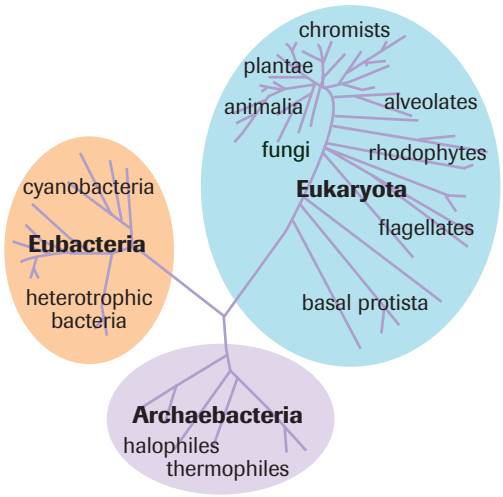
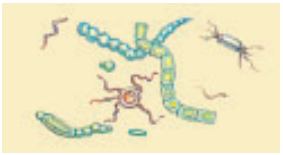


Figure 7
A three-domain system of classification

Table 2 A Six-Kingdom System of Classification

	Kingdom	General characteristics	Cell wall	Representative organisms
	1. Eubacteria	• simple organisms lacking nuclei (prokaryotic) • either heterotrophs or autotrophs • all can reproduce asexually • live nearly everywhere	often present (contains peptidoglycan)	bacteria, cyanobacteria
	2. Archaebacteria	• prokaryotic • heterotrophs • live in salt lakes, hot springs, animal guts	present (does not contain peptidoglycan)	methanogens, extreme thermophiles, extreme halophiles
	3. Protista	• most are single-celled; some are multicellular organisms; eukaryotic • some are autotrophs, some heterotrophs, some both • reproduce sexually and asexually • live in aquatic or moist habitats	absent	algae, protozoa
	4. Fungi	• most are multicellular • all are heterotrophs • reproduce sexually and asexually • most are terrestrial	present	mushrooms, yeasts, bread moulds
	5. Plantae	• all are multicellular • all are autotrophs • reproduce sexually and asexually • most are terrestrial	present	mosses, ferns, conifers, flowering plants
	6. Animalia	• all are multicellular • all are heterotrophs • most reproduce sexually • live in terrestrial and aquatic habitats	absent	sponges, worms, lobsters, starfish, fish, reptiles, birds, mammals

Practice

1. Describe a situation in which classification affects your life.
2. What is meant by the term *binomial nomenclature*?
3. Indicate the advantage of using a Latin name over a common (e.g., English) name. Provide at least one example.
4. List, in order, the major levels of classification, starting with kingdom.

phylogeny the history of the evolution of a species or a group of organisms

Today, most scientists believe that organisms have changed over time. The history of the evolution of organisms is called **phylogeny**. Relationships are often shown in a type of diagram called a phylogenetic tree, where the tree starts from the most ancestral form and includes branchings that lead to all of its descendants. **Figure 8** shows an overall picture of the relationships, but more specific diagrams are possible.

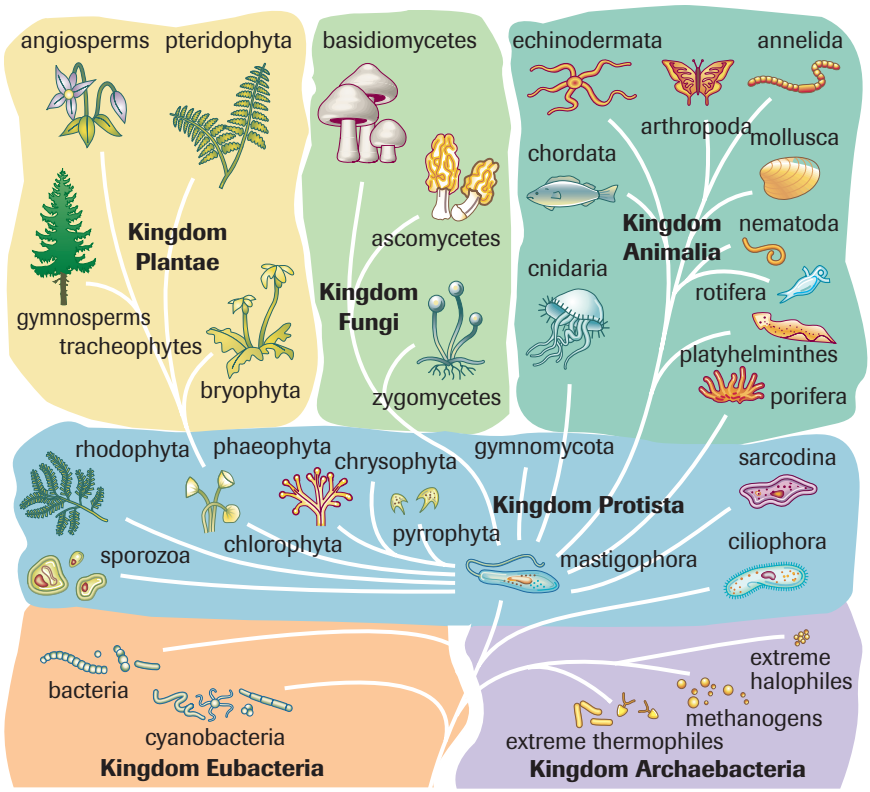


Figure 8
This phylogenetic tree shows relationships within the six kingdoms.

dichotomous key a two-part key used to identify living things. *Di* means "two."

Many scientists regularly use classification manuals to conduct their identification work. Usually it involves the use of a **dichotomous key**. The key is constructed so that a series of choices must be made, and each choice leads to a new branch of the key. If choices are made accurately, the end result is the name of the organism being identified.

INVESTIGATION 5.1 *Introduction*

Using a Classification Key

Whale species are quite variable. For example, some whales are as small as 3.5 m in length, whereas others can reach 25 m or more. Nevertheless, whales can be classified into two general groups. In this investigation, you will use a classification key to group different whales into species.

Report Checklist

● Purpose	● Design	● Analysis
● Problem	○ Materials	○ Evaluation
○ Hypothesis	● Procedure	● Synthesis
● Prediction	● Evidence	

To perform this investigation, turn to page 162.

SUMMARY Classification of Organisms

- Taxonomy is used to help biologists identify organisms and recognize natural groupings of living things.
- Different organisms have different scientific names, which consist of a genus name and a species name.
- In taxonomy, there are seven main taxa arranged in order: kingdom, phylum, class, order, family, genus, and species. The taxa are used to group organisms by their similarities according to structure and/or evolutionary history.

Section 5.1 Questions

1. What is a phylogenetic tree?
2. Why is the classification of organisms important?
3. Discuss the importance of the use of scientific names in the study of biology.
4. Why is phylogeny sometimes called the foundation of taxonomy?
5. Which of the kingdoms is at the bottom of a phylogenetic tree? Why is it placed there?
6. The following is a list of some Latin (Lat.) and Greek (Gr.) words and their English definitions:
   - alopekos (Gr.): fox
   - felis (Lat.): cat
   - articus (Lat.): arctic
   - pous (Gr.): foot
   - canis (Lat.): dog
   - alpinous (Lat.): mountain
   - lagos (Lat.) or lepus (Gr.): rabbit
   - aquaticus (Lat.): found in water
   - mephitis (Lat.): bad odour
   - rufus (Lat.): reddish

   Match each scientific name with the correct common name.

   (a) *Felis concolor* (i) arctic shrew
   (b) *Sorex arcticus* (ii) swamp rabbit
   (c) *Canis rufus* (iii) skunk
   (d) *Mephitis mephitis* (iv) red wolf
   (e) *Alopex lagopus* (v) alpine chipmunk
   (f) *Eutamias alpinus* (vi) arctic fox
   (g) *Sciurus arizonensis* (vii) mountain lion
   (h) *Sylvilagus aquaticus* (viii) Arizona grey squirrel
7. Use the information in **Table 3** to answer the following questions.
   (a) Which of the species are the most closely related? Explain.
   (b) Is the river otter more closely related to the muskrat or the weasel? Why?
   (c) Is the groundhog more closely related to the chipmunk or the ferret? Why?
   (d) Which of the species is (are) the closest relative(s) of the squirrel? Explain.

Table 3 Names of Some Common Mammals

Common name	Scientific name	Family
red squirrel	*Tamiasciurus hudsonicus*	Sciuridae
shorttail weasel	*Mustela erminea*	Mustelidae
groundhog	*Marmota monax*	Sciuridae
mink	*Mustela vison*	Mustelidae
eastern chipmunk	*Tamias striatus*	Sciuridae
river otter	*Lutra canadensis*	Mustelidae
fisher	*Martes pennanti*	Mustelidae
muskrat	*Ondatra zibethica*	Cricetidae
black-footed ferret	*Mustela nigripes*	Mustelidae

5.2 Evidence of a Changing Earth

As you saw earlier, the populations in an ecosystem change in response to changes in the environment. The introduction of a new species or a shift in the amount of nutrients can dramatically affect the equilibrium of the ecosystem. In fact, it is predicted that within your lifetime, changes to Earth's ecosystems will cause the extinction of many species. Have changes in the populations of organisms always occurred? How have these affected living species? Although it is impossible to directly observe what Earth was like millions of years ago, indirect evidence suggests that the types of organisms that lived in the past were very different from those of today. This evidence suggests that modern species evolved from ancestral ones.

Evidence for evolution comes from many lines of investigation. Some evidence comes from direct observation and experiment, while other evidence is more indirect. In the following sections, we examine scientific evidence gathered from the fossil record, the geographic distribution of species, comparative anatomy and embryology, behaviour, plant and animal breeding, and biochemistry and genetics.

DID YOU KNOW ?

The Scientific Method

Francis Bacon (1561–1626) first proposed the scientific method, one way of finding out about the world around us. Bacon devised a method of testing a hypothesis using a controlled experiment. At about the same time, Galileo was using a telescope to provide compelling evidence that Earth was not the centre of the universe—a finding that contradicted the teachings of the church at the time.

paleontology the study of fossils

EXTENSION

Fossil Formation

Fossils are commonly formed when the bodies of organisms become trapped in sediments. In this extension activity, you will find out how this process occurs.

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Evidence from Fossils

Strong evidence of a changing Earth can be seen from a careful examination of fossils. **Paleontology** (the study of fossils) has a central position in the study of evolution. Scientists have discovered approximately 250 000 fossil species, a number thought to represent only a fraction of the species that have lived on Earth. Burrows, footprints, and even chemical remains can fossilize. A complete set of fossils of all previous existing life forms will never be uncovered, since most organisms leave no evidence of their existence. However, fossilized remains, impressions, and traces of organisms from past geological ages provide scientists with direct physical evidence of past life. What patterns have been found in this album in rock?

mini Investigation Puzzling over Evidence

Biologists investigate the natural world through methodical observation and experimentation. As they accumulate evidence, they continually form and test tentative hypotheses toward the development of a theory. In this activity, you model this process by gathering and interpreting evidence, in order to develop and test hypotheses.

- Remove eight puzzle pieces at random from your group's "Evidence" envelope.
- Arrange the pieces on your desk. Discuss the evidence and make predictions about the missing puzzle pieces. Record the predictions in your notebook as your group's first tentative hypotheses.
- Remove two more puzzle pieces from the "Evidence" envelope.
- Add to and modify your original arrangement of puzzle pieces. Comment on the validity of your original hypotheses. Make and record a second set of hypotheses.
- Repeat the above process of obtaining new evidence and modifying your previous hypotheses. At some point you may wish to propose a theory—a tentative explanation that accounts for all the evidence.

(a) In what way do the puzzle pieces model evidence in science?

(b) What scientific processes were you modelling when you arranged your puzzle pieces?

(c) How did you test your hypotheses? How do scientists test hypotheses?

(d) Do you think it is possible to make valid predictions and develop valid theories even when you don't have all the evidence? Explain your reasoning.

(e) How does the "accumulation" of more and more evidence influence your ability to make predictions and/or formulate and test a theory?

1. Different species lived on Earth at various times in the past. Very few of today's species were alive even 1 million years ago, and almost all of the species that have lived are now extinct.
2. The complexity of living organisms generally increases from the most distant past to the present. When fossil deposits are arranged from most ancient to most recent, there is an obvious and systematic progression from only very simple organisms to species of ever-increasing complexity.
3. Living species and their most closely matching fossils are typically located in the same geographic region. For example, all fossils of ancient sloths are found in Central and South America, the only region in which modern, but smaller and very different, species of sloth live today (**Figure 1**).





Figure 1
(a) sloth skeleton **(b)** living sloth

Dating the Past

By the early 1800s, evidence from geology strongly suggested that Earth might be hundreds of millions of years old, much older than the thousands of years assumed at the time. In his 1830 book, *Principles of Geology*, Sir Charles Lyell revolutionized geology with his argument that most geological change was slow and gradual and had been going on over vast expanses of time. Lyell based his theories on his observations of fossil deposits and of geological processes such as erosion and sedimentation.

However, Lyell's conclusions were not widely accepted and were severely attacked by Lord Kelvin, the most respected physicist of the day. Kelvin estimated that Earth was 15 to 20 million years old, based on rigorous mathematical and scientific calculations that assumed that Earth was gradually cooling down. Even though his estimate conflicted with the geological evidence, it agreed with the most widely held beliefs of the time.

In 1903, radioactivity was discovered, a source of heat energy. Kelvin's model had grossly underestimated the age of Earth because it had failed to account for the heat that is continuously generated within Earth by radioactive decay. Radioactive decay also provides a form of geologic clock, giving scientists a means to determine the absolute age of the Earth with great precision.

Radioactive decay changes a particular atom (parent isotope) into a daughter isotope of the same or a different element. For example, radioactive potassium 40 decays to become argon 40 or calcium 40, while uranium 238 decays into lead 206. Physicists measure these decay rates in units called half-lives, the amount of time it takes for half of a sample of the isotope to decay and become stable. They have determined that the

DID YOU KNOW

The Burgess Shale

Fossil beds in the Burgess Shale in British Columbia likely formed through a series of mudslides, which buried living organisms in moving sediment. The resulting fossils are superbly preserved (**Figure 2**). Many of the animals had unusual body forms not found in present-day animals. Discovered in 1909 by Charles D. Walcott of the Smithsonian Institute, it was immediately declared the most important geological find in the world. The Burgess Shale fossil beds became a UNESCO World Heritage Site in 1981.

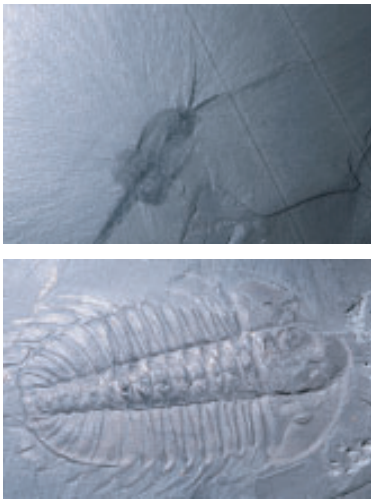


Figure 2

CAREER CONNECTION

Paleontologist

Paleontologists work with fossils to explore the organisms found in various regions over Earth's history. Most paleontologists are college or university professors, but some also work for museums or for petroleum and mining companies. Find out what qualifications are needed for a career in paleontology.

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half-life for any particular isotope is a constant; it is not affected by temperature, moisture, or other environmental conditions. With constant half-lives, isotopes can be used as naturally occurring and extremely precise radiometric clocks.

radiometric dating a technique used to determine the age of a rock or fossil

By measuring the age of rock through these **radiometric dating** techniques, modern paleontologists can estimate accurate ages for fossils. Radiometric dating using a single isotope is not perfect, but when data from a variety of isotopes are combined, scientists can provide age estimates with a very small margin of error. The oldest fossils of living things discovered thus far date to approximately 3.8 billion years.

EXTENSION

Radiometric Dating

View this animation of dating a fossilized mollusc by radiometric dating.

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Practice

1. Offer an explanation for the observation that fossils of birds are rare, while fossils of clams are extremely common.
2. What is radiometric dating and of what value is it to paleontologists?

WEB Activity

Case Study—Finding Fossils and Famous Footprints

In 1976, some famous fossils dating from more than 3.6 million years ago were discovered in Tanzania (**Figure 3**). They represent some of the oldest fossil evidence for upright, bipedal, walking—a milestone in human evolution. Complete this online activity to find out more about these fossils and be introduced to Lucy!

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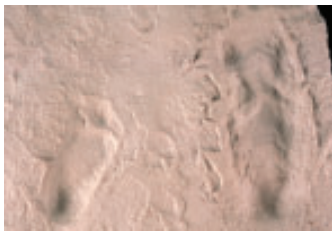


Figure 3

Evidence from Biogeography

biogeography the study of the geographic distribution of life on Earth

endemic a term used to describe a species that is found in one location only

Biogeography explores the variation and distribution of life over Earth's surface, both today and in the past. Patterns of geographic distribution provide important clues to the history of life on Earth.

Over long periods of time, Earth's landmasses have undergone dramatic changes by the process of continental drift. About 225 million years ago, Earth's continents were part of one landmass. The slow drift of Earth's tectonic plates eventually separated the ancient landmasses into the continents we see today. As a result, fossils of some species that date to 150 million years ago and older were once in the same geographic region, but are now distributed on different continents (**Figure 4**, next page). After the continents separated, most species younger than about 150 million years were restricted to separate continents. Most recent fossils of the same species are not found on these different continents. This strongly suggests they evolved *after* the breakup of the continents.

Islands that are far removed from landmasses are also of great interest to evolutionary biologists. Many of these islands are products of volcanic activity, and were barren ash and rock when they first were formed. Remote islands are homes to unique species, many of which are **endemic** (found nowhere else). This suggests that these species have evolved in isolation. Scientists hypothesize that the ancestors of endemic species came from other landmasses. But how? Any ancestors would have had to cross great distances of open ocean, and so most likely were animals capable of flight (birds and insects) and seeds carried by the wind or the sea. Other species may have travelled on rafts of vegetation or ice floes. Is there any evidence to support these conclusions?

DID YOU KNOW ?

The Royal Tyrrell Museum

The Royal Tyrrell Museum opened in 1985, commemorating Joseph Burr Tyrrell, the man credited with finding the first dinosaur fossils in the Drumheller Valley, Alberta, in 1884. You can view the museum's fabulous fossil collection or find out about its many active programs in person or online.

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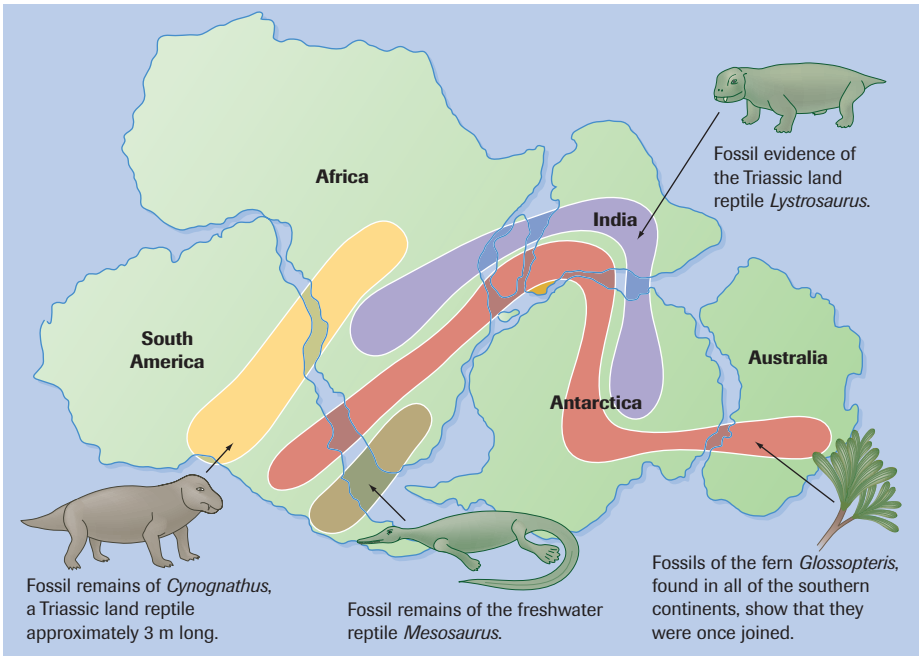


Figure 4
Fossil remains of species that lived more than 150 million years ago can be found on many continents. Fossils of more recent species (not shown) are found on separate continents.

DID YOU KNOW?

Flightless Birds

Virtually all of the world's large remote islands are home to unique species of flightless, ground-nesting birds. Even when very similar islands are separated by only short distances of open ocean, distinct species occur.

There is. The native species on remote islands are invariably and exclusively birds, insects, and other potentially mobile organisms. For example, the Hawaiian Islands are located in the Pacific Ocean, 3200 km from any continent. Species native to these islands include 0 native reptiles or amphibians, 2 native mammals—the monk seal and the hoary bat, 96 species of birds, and many, many insect species. Additionally, genetic testing of Hawaiian plants strongly suggests that the 1729 native species and varieties known today all descended from only 272 founding species.

SUMMARY *Evidence of a Changing Earth*

- Fossil evidence reveals that species living today are different from those living in the past.
- Fossils reveal a progression of different species on Earth over time, from simple forms in the most distant past to increasingly complex forms.
- Radiometric dating allows scientists to accurately determine the ages of rocks and fossils.
- Evidence from biogeography suggests that different species evolved independently in isolated parts of the world.

Section 5.2 Questions

1. Explain how the following patterns of fossils offer compelling evidence for evolution:
   (a) the relationship between the age of fossils and the kinds and complexity of fossils
   (b) the relationship between the geographical location of both fossils and living species
2. Would you expect to find more unique species on remote islands, such as Iceland, or islands that are close to a large landmass, such as the Queen Charlotte Islands? Give reasons for your answer.
3. Brainstorm a list of living plants and animals that you think might be able to reach the Hawaiian Islands from the coast of British Columbia. Be prepared to defend your choices.

Extension

4. Research carbon 14 (^{14}C) dating techniques, including why the percentage of ^{14}C begins to change after an organism dies. Report your findings to your class.

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5.3 Evidence of Evolution from Biology

homologous features features with similar structures but different functions

analogous features features that are similar in appearance and function, but do not appear to have the same evolutionary origin

A comparison of the physical anatomy and genetic makeup of organisms also provides evidence to support the theory that modern species evolved from ancestral species. Some of this evidence will be presented in this section.

Evidence from Anatomy

The forelimbs of a bird, whale, horse, and human all share very similar bone arrangements, even though they serve very different functions (**Figure 1**). These observations strongly suggest that an ancestral forelimb evolved modifications that better served new functions. Such features, with similar structure but different functions, are called **homologous features**. In contrast, **analogous features** are similar in appearance and in function, but do not appear to have the same evolutionary origin, such as a bird's wing and an insect's wing.

An evolutionary relationship among species is also evidenced in embryonic development (**Figure 2**). In the early weeks of development, human embryos possess a tail and gill slits, similar to those in chicken and fish embryos. The embryonic tail serves no function in humans and later forms a rudimentary tailbone. The gill slits become modified in both humans and birds to form various internal structures, including bones of the inner ear.

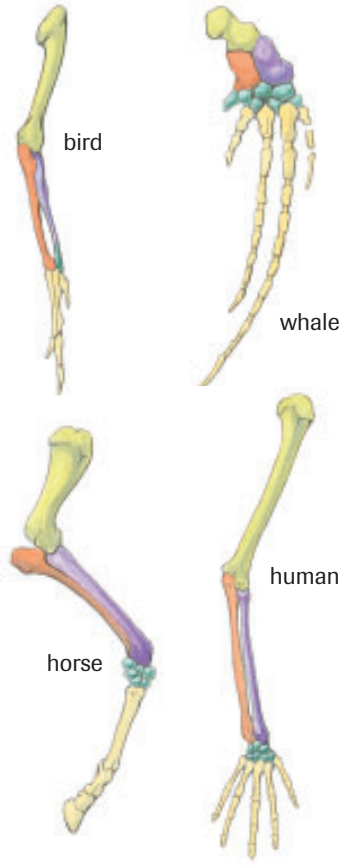


Figure 1
The forelimbs of each of these organisms are adapted to carry out very different functions, yet they all possess very similar bone structure.

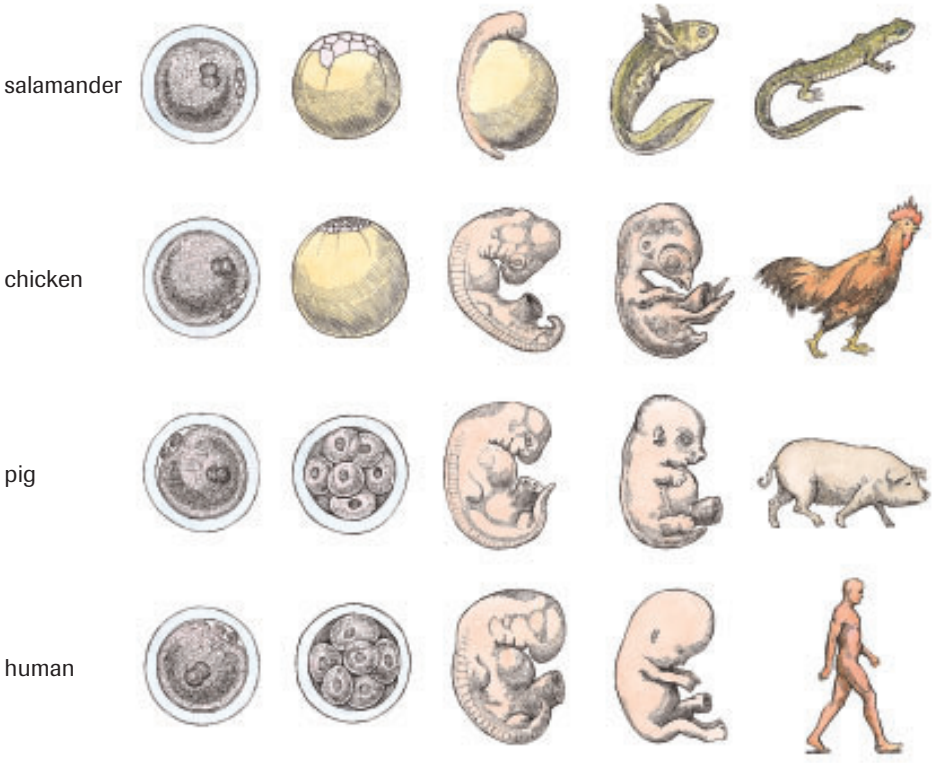


Figure 2
Homologous features such as tailbones are clearly evident in the embryos of these organisms.

Vestigial Features and Anatomical Oddities

Vestigial features are rudimentary structures that serve no useful function. Such features are present in virtually all species and provide perhaps the most compelling evidence for evolution. A reasonable explanation for vestigial features is that they once served some function in an ancient ancestor. Some modern species of whales and snakes have vestigial hip and leg bones—evidence that suggests they evolved from ancestors that walked on four limbs (**Figure 3**). Similarly, many mammals have vestigial toe bones elevated above the ground (**Figure 4**). Some beetles even have fully developed wings, trapped beneath fused covers. Blind cave salamanders have empty eye sockets, suggesting that they evolved from salamanders with fully functioning eyes.

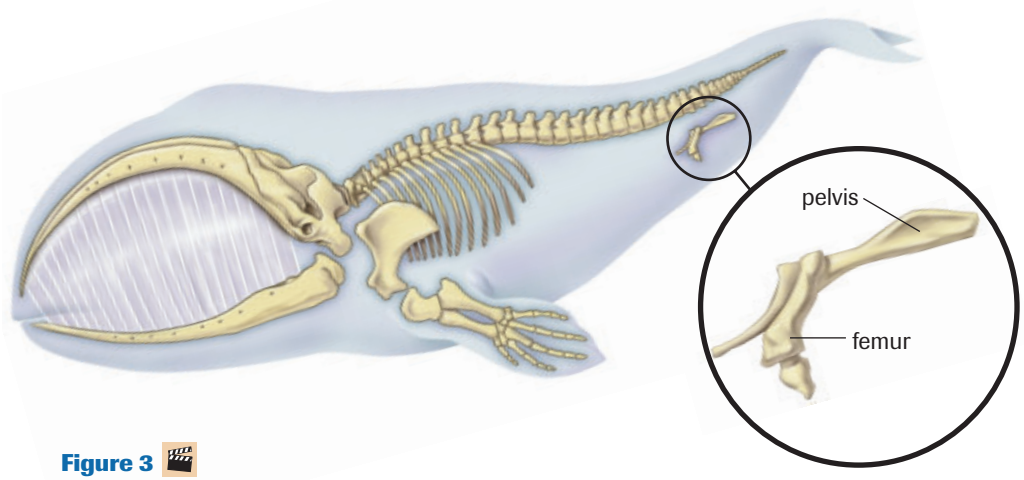


Figure 3
Whale skeletons have vestigial hip and leg bones.

Practice

1. The shells of crabs and turtles serve a similar purpose. Are they homologous or analogous traits? What evidence did you use to reach your conclusion?
2. Would you consider human body hair to be a vestigial feature? Support your answer.

vestigial features rudimentary structures with no useful function

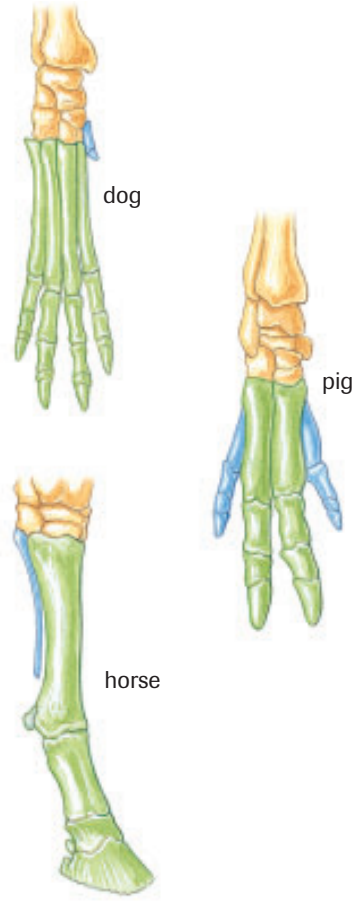


Figure 4
Dogs, pigs, and horses have at least one vestigial toe (blue). Although the bones remain, these digits no longer serve a purpose.

mini Investigation — Variations on a Theme

The forelimbs of different vertebrates are well adapted to serve specific functions. However, hypothesizing the potential adaptive advantage of such homologous features is not always easy. **Table 1** lists bird species with very different bills.

- Use print and Internet resources to explore the bill shapes of six of these species. Choose four species that are living (extant) and two that are extinct.

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(a) How does the shape of each bill contribute to the species' success?
(b) Write a hypothesis that explains the adaptive significance of each bill shape.

Table 1 Birds with Unique Bill Shapes

Extant	Extinct
pelican	dodo
nighthawk	diatryma
falcon	gastornis
bittern	
toucan	
hummingbird	
flamingo	
skimmer	
spoonbill	

EXTENSION

Nucleotide Sequences and Amino Acids

This Audio Clip describes how the sequence of nucleotides found in the genes determines which amino acids make up each protein. If the DNA is changed through a mutation, this can change the final protein product.

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Evidence from Biochemistry

Evidence for evolution has also been found by comparing biochemical characteristics of different species. Proteins are molecules that make up many structures in organisms, such as muscle cells and skin cells. Proteins are made up of long chains of amino acids, and each type of protein has a unique number and sequence of amino acids. Many species possess similar proteins. Studies suggest that, over time, similar proteins in different species become increasingly different in terms of their amino acid sequences. For example, hemoglobin is an oxygen-carrying protein present in all vertebrates. When scientists determined the amino-acid sequence of hemoglobin from different species, they found that the sequence varied. The differences were greater between species that were less similar overall, such as a macaque and a lamprey (**Figure 5**). This is evidence that, over time, the hemoglobin molecules evolved to have different characteristics.

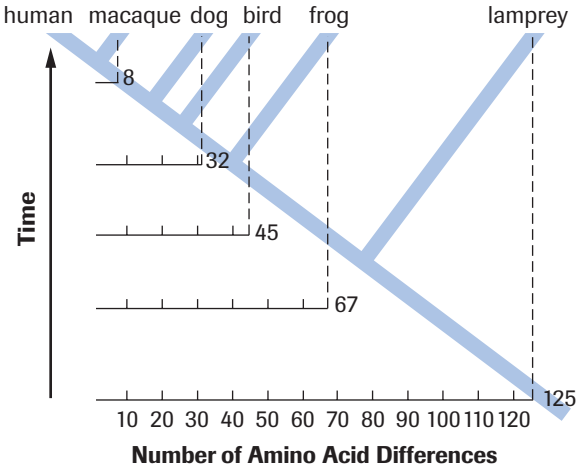


Figure 5
Differences in amino acid sequences in a portion of the hemoglobin protein reflect the degree of similarity among different species.

DNA the molecule that makes up genetic material

gene a segment of DNA that performs a specific function, such as coding for a particular protein

Scientists have also found evidence for evolution in DNA sequences. **DNA** (deoxyribose nucleic acid) is the hereditary material that determines which characteristics are passed on to the next generation. Every organism has a particular set of characteristics, or traits, that are inherited, such as eye colour in humans. Each DNA molecule contains many different **genes** that provide the instructions for these traits. Genes determine the particular traits of an individual, such as brown eye colour or green eye colour.

DNA is composed of four chemicals called nucleotide bases, or simply bases, arranged in different sequences (**Figure 6**). The four bases in DNA are adenine (A), thymine (T), cytosine (C), and guanine (G). DNA sequences from different species that code for the same protein vary in the number and order of the nucleotides.

cow AGTCCCCAAAGTGAAGGAGA CTATGGTTCCTAAGCACAAG GAAATGCCCTTCCCTAAATA

Figure 6
This is a segment of DNA from cows that codes for a milk protein.

Just as early biologists discovered homologous and vestigial *anatomical* features, geneticists have found large numbers of both homologous and vestigial *genes* in the DNA of virtually all species. For example, humans possess a set of defective genes that would allow us to make our own vitamin C. We have lost both the ability and the need to make vitamin C but still possess the useless genetic instructions to do so.

LAB EXERCISE 5.A

Evidence from Genetics

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	○ Evaluation
○ Hypothesis	○ Procedure	○ Synthesis
○ Prediction	● Evidence	

DNA fingerprinting is now used widely in criminal investigations. With this technique, forensic scientists can determine the probability that a DNA sample is from a particular individual or a close relative, with an unprecedented degree of certainty. DNA samples obtained from closely related individuals have more of the same DNA sequences; samples from the same individual are identical. This same principle applies to the DNA sequences from different species. More closely related species are more likely to have more similarities in the sequence of their DNA. In this activity, you will compare sequences of DNA from different species to infer their phylogeny, or kinship.

The Closest of Kin

The sequences of real data in **Figure 7** represent a segment of DNA that codes for the same milk protein in six different species. Each letter represents one nucleotide base in the DNA segment. The letters have been vertically aligned and colour coded to highlight similarities and differences between the species. Use the following guidelines to assist you in analyzing this DNA information:

- Only a shared difference offers evidence of evolutionary kinship. It suggests species may have inherited the difference from a common ancestor.
- The more base differences species have in common, the more likely they are to be closely related.
- Base sequences common to all species offer no useful information about relationships.
- A difference exhibited by only one species offers no information about kinship.

Evidence

(a) Design and construct a data table or spreadsheet that can be used to tabulate the numbers of shared differences between each possible pair of species.

(b) Tabulate your data.

Analysis

(c) Which pair of species had the greatest number of shared differences in their bases?

(d) Based on this evidence, what species is most closely related to the

(i) deer (ii) peccary (iii) whale?

(e) What evidence suggests that whales may be more closely related to cows than they are to pigs?

	143 ▼	▼▼	162 ▼	166 ▼▼	▼	▼▼	182 ▼	▼
cow	AGTCCCCAAAGTGAAGGAGA		CTATGGTTCCTAAGCACAAG				GAAATGCCCTTCCCTAAATA	
deer	AGTCTCCGAAGTGXAGGAGA		CTATGGTTCCTAAGCACGAA				GAAATGCCCTTCCCTAAATA	
whale	AGTCCCCAXAGCTAAGGAGA		CTATCCTTCCTAAGCATAAA				GAAATGCGCTTCCCTAAATC	
hippopotamus	AGTCCCCAAAGCAAAGGAGA		CTATCCTTCCTAAGCATAAA				GAAATGCCCTTCTCTAAATC	
pig	AGATTCCAAAGCTAAGGAGA		CCATTGTTCCCAAGCGTAAA				GGAATGCCCTTCCCTAAATC	
peccary	AGACCCCAAACCTAAGGAGA		CCGTTGTTCACAAGCGTAAA				GGAATGTCCTCCCCTAAATC	

Figure 7
These base sequences include positions 141–200 of a portion of the DNA molecules encoding a milk protein in six mammal species. Coloured bases indicate genetic changes shared by more than one species. The "X" denotes a base for which the original DNA sequencing data were inconclusive.

Evidence from Artificial Selection

artificial selection the process of humans selecting and breeding individuals with the desired traits

Since the beginning of agriculture, humans have used artificial selection to alter the appearance, behaviour, and even chemical makeup of plants and animals. They select the individuals with the desired traits, breed them, and then pick the best offspring to breed again. Today's domestic animals and crop plants have been artificially selected over many hundreds of generations. **Artificial selection** is another word for plant and animal breeding, in which people breed individuals with desired characteristics in order to get offspring with those same characteristics.

As an example, did you know that cabbage, broccoli, cauliflower, and ornamental kale are all the same plant species? Over the centuries, farmers and plant breeders selected characteristics of a single plant species, the sea cabbage, to produce a range of edible and ornamental varieties (**Figure 8**). The fact that humans can use artificial selection to produce such dramatic changes in species over relatively short periods of time provides compelling evidence that similar and even more dramatic changes occur in nature over millions of years and countless generations.

CAREER CONNECTION

Breeder

Plant and animal breeders use artificial selection to modify crops and livestock to have traits that are useful for humans. Breeders may work at universities, colleges, corporations, or directly in agricultural production.

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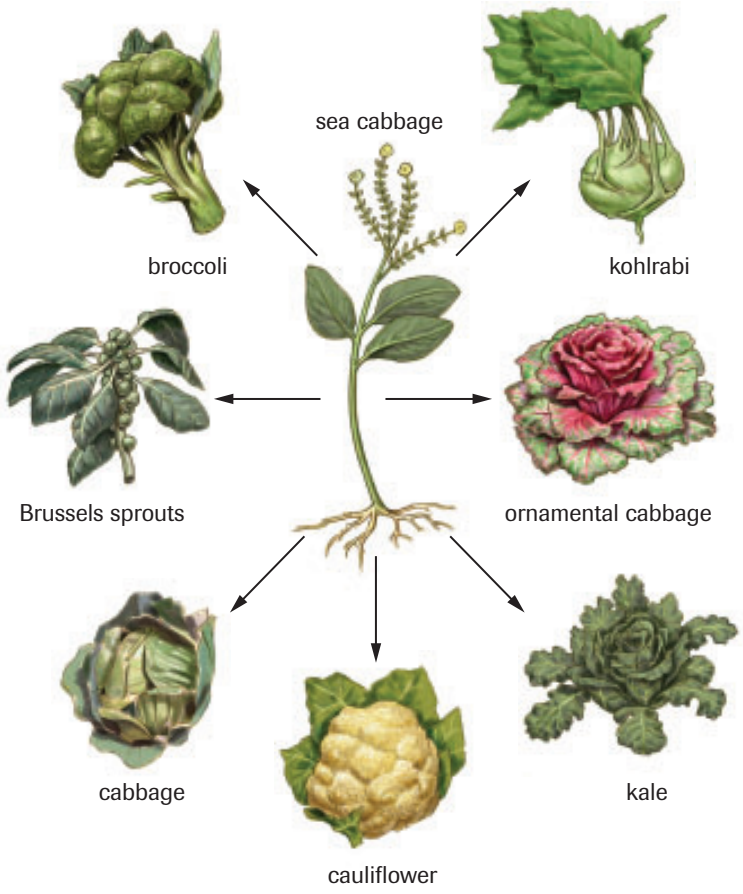


Figure 8
Artificial selection over many generations produced a range of useful varieties from sea cabbage.

WEB Activity

Case Study—Were Neanderthals Humans?

In the late 1990s, several samples of DNA were successfully extracted from the teeth of well-preserved Neanderthal fossils. The DNA was then copied and sequenced.

In this activity, you will go online to compare the actual DNA sequences of ancient Neanderthals, modern humans, and chimpanzees. Note that this research involved the analysis of mtDNA, DNA that is present within the mitochondria of all cells.

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SUMMARY *Evidence of Evolution from Biology*

- Multiple lines of evidence suggest species have a shared ancestry.
- Homologous and vestigial features provide evidence of specific changes.
- DNA analysis can be used to reveal phylogenetic relationships between different species or groups.

Section 5.3 Questions

1. For each of the following vestigial features, write a hypothesis for its ancient function and indicate a change that may have led to the loss of this function. Show your answer in a graphic organizer.
   (a) pelvic (hip) bones in some whales
   (b) elevated toe on hind leg of deer
   (c) human "goosebumps"
   (d) human muscles for moving the outer ear
   (e) rudimentary wings in flightless insects, such as earwigs
2. Dolphin flippers contain a wrist and set of digit bones and associated muscles. Explain how this provides evidence that cats and dolphins share a common evolutionary origin.

Extension

3. Examine **Figure 9**. Each of these series of letters represents the partial sequence of amino acids for the same type of protein in each of six different species. Each letter represents a specific kind of amino acid. Highlighted letters show differences in the sequence as compared to that of the chicken. The order and type of each amino acid is coded by inherited genetic information. Therefore, based on evolutionary theory, we would expect more closely related species to have more similar sequences.

Species: tuna, turtle, dog, screwworm fly, penguin.

chicken	GDIEKGKKIFVQGKCSQCH
_____	GDVEKGKKIFVQGRCAQCH
_____	GDIEKGKKIFVQGKCSOCH
_____	GDVAKGKKTFVQGKCAQCH
_____	GDVEKGKKIFVQGKCAQCH
_____	GDVEKGKKIFVQGKCAQCH

Figure 9

Based on this evidence, compare each sequence to that of the chicken, and match each species with its most probable sequence.

4. New Zealand scientist David Lambert collected DNA samples from 7000-year-old nesting grounds of the Adélie penguin in Antarctica. He collected wonderfully preserved DNA samples from ancient frozen bones in layers of ice directly beneath the present-day nesting colonies. Use the Internet to learn his findings. What does Lambert's evidence suggest about the rate of evolutionary change in this species of penguin?

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5.4 The Making of a Theory—Accounting for the Evidence



Figure 1
Charles Darwin

spontaneous generation the belief that living things arose from non-living matter

inheritance of acquired characteristics the false concept of inheritance of features acquired during the life of an individual



Figure 2
Lamarck believed that the long neck of a giraffe came from generations spent reaching for food.

A scientific theory is a model that accounts for all of the known scientific evidence as completely as possible. It provides a plausible explanation of how things in nature are related and enables scientists to make testable predictions. As evidence accumulates, scientists alter or modify a theory to fit the new data.

Before the 18th century, it was widely believed that living things were "fixed" and that they retained the same form from when they first appeared on Earth. During the second half of the 18th century, a number of scholars began to speculate and speak out on the issue of evolution. Georges-Louis Leclerc de Buffon, a leading naturalist, proposed that species could change over time and that these changes could lead to new organisms. Similar views were put forth in 1760 by Carl Linnaeus, the founder of biological nomenclature, and in 1794 by Erasmus Darwin, the grandfather of Charles Darwin (**Figure 1**). Linnaeus proposed that the few species at creation had become hybrids, which had then formed many new species. Erasmus Darwin presented a strong case for the idea that all life had developed from a single source. Such ideas were not widely accepted.

Lamarck's Theory

In the early 1800s, a student of Buffon, Jean-Baptiste Pierre Antoine de Monet Chevalier de Lamarck, presented the first theory of evolution that included a *mechanism*. Lamarck believed that new, very simple species were continually being created by **spontaneous generation** (by arising spontaneously from non-living matter), and then gradually became more complex. He believed that organisms had a "force" or "desire" that led them to change for the better, and that organisms must be able to produce new parts to satisfy these needs and become better adapted to their environment. Lamarck reasoned that the use and disuse of certain structures could be passed on to the offspring. For example, Lamarck proposed that one generation of giraffe might have had to obtain food that was higher in trees. The continual stretching of the neck would lead to a slight elongation of the neck over a lifetime. Lamarck postulated that this acquired trait, a slightly longer neck, would be inherited by offspring. This pattern of inheritance over many generations eventually led to the very long necks now found in the giraffe (**Figure 2**). Today the term "Lamarckism" is used to describe the concept of **inheritance of acquired characteristics**. We now know that acquired traits cannot be inherited, but Lamarck did recognize that the environment played a role in driving evolutionary change.

Practice

1. Make a two-column chart with the headings "Inherited traits" and "Acquired traits."
   (a) In each column, write examples of your own traits (these can be physical or behavioural).
   (b) Which, if any, of your inherited traits could be altered during your life? How?
   (c) Which, if any, of your acquired traits can be passed on to your offspring? How?

Darwin's Theory

In 1831, Charles Darwin set sail on HMS *Beagle* to travel around the world. He returned in 1836 filled with enthusiasm and questions about what he had seen and experienced. The following list highlights some of the now famous evidence Darwin gathered while on his voyage and the inferences he would later draw from them:

1. In South America, Darwin observed unusual fossil species that resembled giant variations of the sloths and armadillos living in the same region. He suspected that the living forms might have descended from the fossilized species.
2. He noted that species living in the South American tropics did not resemble those living in the African tropics. Instead, they were more like the species living in cooler parts of South America. He inferred that each such landmass might have acted like an isolated nursery, in which sets of species had evolved independently.
3. The harsh landscape of the Galapagos Islands was home to 13 very similar species of finches (**Figure 3**). Found nowhere else on Earth, these birds most closely resembled species living in a very different habitat on the coast of South America, 1000 km to the east. Darwin speculated that they had all evolved from a single species that had arrived in the Galapagos from South America.
4. Darwin observed fossil deposits of corals at an elevation of 3000 m in the Andes Mountains. After experiencing a severe earthquake that lifted portions of the coastline 3 m upward, Darwin became convinced that such geological forces, given vast expanses of time, could account for the location of the fossils and the mountains.

Long after his voyage, Darwin continued to gather evidence, performing thousands of experiments and bombarding experts in every field of biology with questions. He became keenly interested in artificial selection, soon recognizing that all species possessed inherited variations that could be selected to change the traits of a species in desirable ways. Darwin reasoned that if people could alter the appearance and behaviour of species through artificial selection, then the environment could have a similar selective effect on wild species.

Darwin found the final piece of his puzzle in a mathematics paper written in 1778 by Thomas Malthus, *Essay on the Principle of Population*. Malthus showed that all species produce far more offspring than are able to survive. Darwin realized that, since so many offspring were being born, there must be intense competition among them for suvival. Darwin then put together a workable theory of evolution by **natural selection**. By June of 1858, he had written a quarter of a million words toward a major treatise, when he received a letter from Alfred Russell Wallace, a brilliant naturalist working in Malaysia. Wallace had independently arrived at the same conclusions as Darwin and described his own theory in the letter. Learning of the situation, Darwin's colleagues convinced him to submit a paper along with Wallace's at a meeting on July 1, 1858. A year and a half later, Darwin published *On the Origin of Species by Means of Natural Selection or The Preservation of Favoured Races in the Struggle for Life*. It sold out on the first day. **Table 1** summarizes Darwin and Wallace's Theory of Evolution by Natural Selection.

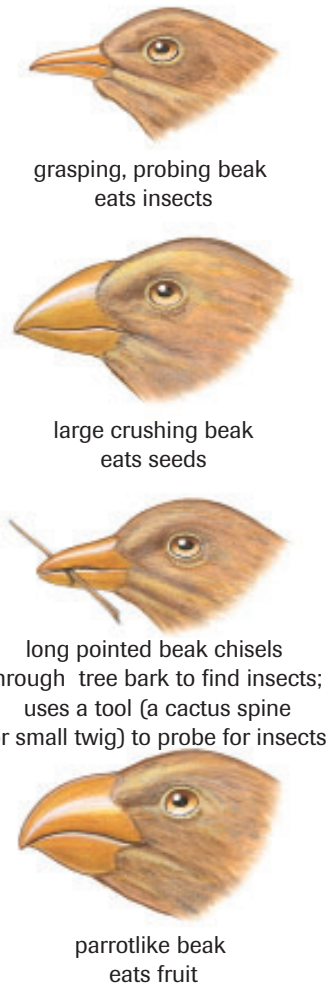


Figure 3
Some of the beak modifications that Darwin noted among the 13 similar species of finches on the Galapagos Islands

Table 1 The Theory of Evolution by Natural Selection

Observation 1	Individuals within any species exhibit many inherited variations.
Observation 2	Every generation produces far more offspring than can survive to reproduce.
Observation 3	Populations of species tend to remain stable in size.
Inference 1	Individuals of the same species are in a constant struggle for survival.
Inference 2	Individuals with more favourable variations are more likely to survive and pass these variations on. Survival is not random. *This* is natural selection.
Inference 3	Since individuals with more favourable variations contribute proportionately more offspring to succeeding generations, their favourable inherited variations will become more common. *This* is evolution.

natural selection the result of differential reproductive success of individuals caused by variations in their inherited characteristics.

Practice

2. After returning from his famous voyage, Darwin began to believe that species could change. What steps did he take to gather evidence to support this possibility?
3. Describe the impact that the principles in Malthus's essay had on Darwin's thinking.

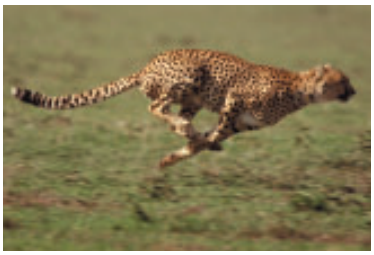


Figure 4
Cheetahs rely on their speed to help them catch their prey.

Natural Selection

How does this process of natural selection operate in nature? Imagine an ancient population of cheetahs with different running speeds. The faster cheetahs probably caught prey more easily and stayed healthier. Such fit individuals might have been better able to compete for mates, provide better nourishment and protection for their young, and lead longer reproductive lives. Natural selection would favour the reproductive success of the faster individuals. Natural selection may therefore account for the running speed in modern-day cheetahs (**Figure 4**).

Darwin's theory is based on a very simple set of observations and logical reasoning. He observed that all species exhibited inherited variations. He reasoned that, because of those differences, some individuals are better adapted to survive and reproduce than others are. Over time, the inherited traits that provided the survival advantage would become more common in the population. The population would have evolved.

Even without evidence from chemistry and genetics, scientists had accumulated sufficient evidence for general agreement that Earth's populations had a history of change by the mid-1800s. This evidence from paleontology, geology, biogeography, anatomy, and artificial selection is consistent with this idea. However, it was not until the early 1900s that scientists formulated a reasonable explanation, or theory, that could explain *how* such change occurred—the *mechanism* of evolution. As you will read in the next section, this was not possible until scientists began to understand how traits are inherited from parent to offspring.

EXTENSION

The Peppered Moth

One example of natural selection at work is the changes in the peppered moth that occured during the Industrial Revolution. You can explore these changes by viewing an animation and then carrying out this extension activity.

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SUMMARY — The Making of a Theory—Accounting for the Evidence

- Buffon, Linnaeus, and Erasmus Darwin were among the first prominent scientists to suggest that species could change over time.
- Lamarck was the first to recognize that the environment played a central role in directing adaptation, and to develop a plausible theory of how evolution might occur—by the inheritance of acquired characteristics.
- Charles Darwin based his theory of evolution by natural selection on evidence from many sources, including his five-year voyage on the *Beagle*.
- Darwin and Wallace's theory of natural selection states that evolution occurs because those individuals best suited for survival contribute a greater proportion of offspring with similar traits to the next generation.

Section 5.4 Questions

1. In some wild deer populations, selection by humans favours the survival of smaller males, since large bucks are preferentially hunted.
   (a) What would you expect to happen to the genetic makeup of this population over time?
   (b) In these populations, will mutations for "small size" occur more often than for "large size"? Explain.
2. Create a table to compare and contrast Lamarck's and Darwin's explanations of the mechanism of evolution.
3. Sir Isaac Newton credited the work of Galileo and others for his own successes, declaring that: "If I have been able to see further, it was only because I stood on the shoulders of giants." Describe the contributions of four scientists on whose work Darwin relied for his achievement.

Sources of Inherited Variation 5.5

Recall that Darwin's theory of natural selection states that individuals that are better adapted to their environment will contribute more offspring to the next generation. These offspring have traits similar to their parents, and so will in turn be better adapted. Over time, natural selection leads to a change in the traits of the species as a whole—that is, to evolution. However, natural selection can only occur when there was variation in the traits of the individuals that make up a species. Where does this variation come from? When Darwin published *On the Origin of Species,* scientists were not able to answer this question. It took until the 1930s until biologists understood enough about genes and their role in inheritance to start to answer this question. Variability in a species may arise from two biological processes: mutations and sexual reproduction.

Mutations

DNA, the hereditary material, is found in the chromosomes of a cell (**Figure 1**). DNA is composed of long sequences of the four nucleotide bases—adenine (A), thymine (T), cytosine (C), and guanine (G). The sequence of these bases forms a code which, when translated by the cell, gives an organism specific inherited traits. Genes are segments of DNA that code for specific traits. Each gene has a specific DNA sequence. DNA is therefore like a blueprint for a particular individual organism.

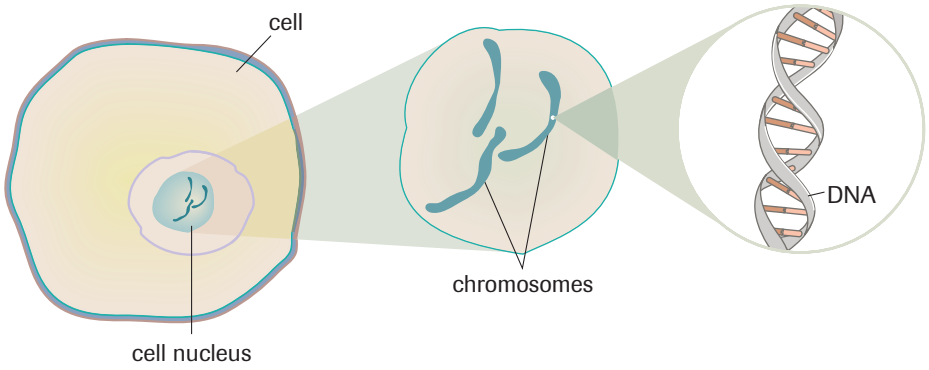


Figure 1
DNA, the genetic material, is packaged in chromosomes in the cell. The DNA molecule is composed of two strands of nucleotide bases.

In most cases, the DNA of an organism will remain the same throughout its life. Sometimes, however, DNA changes occur, and entirely new genetic information can arise. **Mutations** are random changes in the DNA itself, and they provide a continuous supply of new genetic information. Mutations can be caused by environmental factors such as chemicals or radiation, or from errors that arise when cells use or make copies of the DNA molecules. There are many types of mutations. Some involve the loss or duplication of entire sections of DNA, while others may be simple changes to the DNA sequence (**Figure 2**). Mutations are relatively rare in individuals—roughly about one new mutation per sex cell. In large populations reproducing over many generations, however, the number of mutations is substantial.

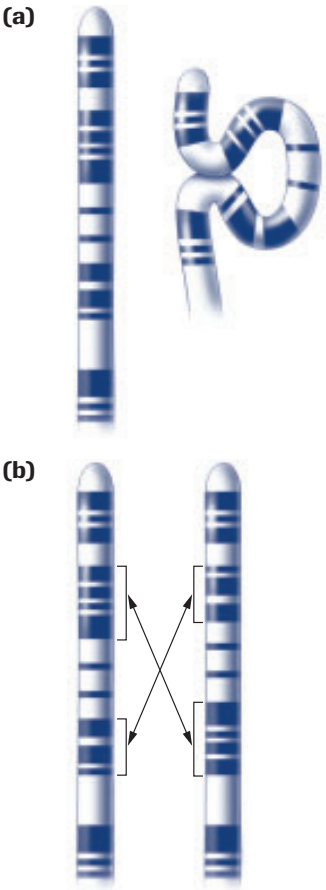


Figure 2
Some mutations result in the reversal of banding patterns along chromosomes. In **(a)**, the chromosome on the right undergoes a mutation in which the looped section breaks and re-attaches in the opposite "flipped" orientation **(b)**.

mutation a change in the DNA sequence in a chromosome

neutral mutation a mutation that has no effect on the organism

fitness an organism's reproductive success

harmful mutation a mutation that reduces an organism's fitness

beneficial mutation a mutation that enhances an organism's fitness

The effects of a mutation depend on what DNA sequence is altered and how it is affected. A **neutral mutation** has no immediate effect on an individual's **fitness**, or reproductive success. A **harmful mutation** reduces an individual's fitness. A **beneficial mutation** gives an individual a selective advantage. Most mutations are neutral or harmful in nature.

There are three common misconceptions about how mutations contribute to evolution. These misconceptions are given in **Table 1**, along with the accepted understanding based on observations.

Table 1 Mutation Misconceptions

Misconception	Accepted Understanding
Mutations occur when "needed," in response to environmental challenges.	Mutations occur at random, with harmful mutations being more common than beneficial mutations. There is no design to it.
Since harmful mutations are more common than beneficial mutations, they can accumulate and the species will steadily degrade.	Harmful mutations are *selected against* and therefore do not accumulate over the generations. The environment favours the fittest organisms. Harmful mutations can reduce or even eliminate the individual's chance of reproductive success.
Since mutations are random or chance events, then evolution is just pure chance.	Although beneficial mutations are rare, they are *selected for* and may accumulate over the generations. Beneficial mutations often give individuals improved survival and reproductive success.

EXTENSION

Mutations and Changes in Proteins

Listen to a discussion of how mutations can cause proteins to change, which might then affect the survival of an organism.

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Practice

1. In your own words, explain the role, if any, that neutral, harmful, and beneficial mutations each play in evolution.

Sexual Reproduction and Variability

asexual reproduction the production of offspring from a single parent; offspring inherit the genes of that parent only

siblings offspring from the same parent (in asexual reproduction) or parents (in sexual reproduction)

sexual reproduction the production of offspring by the union of sex cells from two different parents; the offspring inherit a combination of genes from both parents

In species that undergo **asexual reproduction**, such as bacteria, an individual reproduces without a mate. The offspring receives an identical copy of its parent's DNA. As a result, the offspring has identical traits to its parent and to any other offspring from that parent (**siblings**). The exception to this occurs if there is a mutation in the DNA. As you have read, mutations are relatively rare. As a result, there is very little inherited variability in asexually-reproducing species and very few traits that can be selected by natural selection.

In contrast, there is a great amount of inherited variability in species that undergo **sexual reproduction**. For example, think of the variation among just the people you know. Most plants and animals reproduce sexually. In sexual reproduction, the offspring are never identical to the parents or to other siblings (except for identical twins). Sexually reproducing species therefore have many traits on which natural selection can act.

Why are sexually-reproducing species so variable? There are three reasons.

1. Sexually-reproducing species have two copies of each gene. Each copy of the gene may be identical or different. In sexual reproduction, there are two parents. Both parents contribute one copy of each gene to the offspring. An offspring therefore inherits one copy of each gene from one parent and one copy from the other parent. The offspring therefore has a different combination of genes than either parent, and therefore will have its own unique set of traits.

2. The assortment of genes that an offspring inherits from either parent is determined randomly. Each sibling therefore has a unique combination of genes, and so siblings from sexual reproduction are not identical to each other. (Identical twins are an exception to this.) To illustrate, let's say that a large, black male dog is crossed with a small, brown female dog. A puppy from this cross might inherit any combination of these traits. For example, one puppy might be a large, brown female while another might be a small, black male. (There are other combinations as well.) The greater the number of genes a species has, the larger the number of combinations and the greater the genetic variability of the species as a whole.
3. Sexually reproducing species choose different mates. This process is not always random, but each combination of parents will give rise to different combinations of genes and traits in the next generation. In a small population of 1000 males and 1000 females, there are 1 million different possible mating pairs.

Table 2 connects genetics and Darwin's theory of natural selection.

Table 2 Genetic Mechanisms and Darwin's Theory

Darwinian evolution	Genetic mechanisms
inherited characteristics	Inherited characteristics are determined by genes. Organisms typically possess thousands of different genes.
population variability	Individuals of the same species differ from one another, in part because they possess different combinations of genes. The genetic makeup of all individuals within a population is called the population's **gene pool**.
source of new variations	New traits can arise when genes become mutated.
natural selection	Some genes determine traits that make the individual better suited for survival and reproductive success. Individuals with these traits will produce more offspring, some of which will inherit these advantageous genes.
evolutionary change	Over many generations, individuals carrying the genes that determine the most favourable traits for survival and reproductive success will become more common in the population. Evolution is this change in the population's gene pool.

DID YOU KNOW ?

Thomas Kuhn

A well-known philosophy of scientific thought put forward by Thomas Kuhn in a book published in 1962 proposes that scientific knowledge advances by gradual study and research, interspersed with abrupt jumps forward, known as "paradigm shifts." How might the theory of evolution help to back up Kuhn's philosophy?

gene pool all the genes in a certain population

mini Investigation Genetic Shuffle

In this activity, you will model the amount of possible variation for different numbers of traits in a sexually-reproducing species, using a deck of playing cards. Each card represents the gene for a particular trait. The suits represent the different forms of a gene. Since there are four suits in a deck of card, there are four possible forms for each gene in this model.

Materials: playing cards

- Obtain all four suits for any four different playing cards. Divide them into two sets to represent the genetic makeup of two parents. For example:

  Father: 3 of spades and 3 of clubs;
  8 of spades and 8 of clubs;
  Jack of spades and Jack of clubs;
  King of spades and King of clubs

  Mother: 3 of hearts and 3 of diamonds;
  8 of hearts and 8 of diamonds;
  Jack of hearts and Jack of diamonds;
  King of hearts and King of diamonds

- Using your cards, determine the number of all possible different genetic combinations from the two parents for one of the traits. Record your results in a table or spreadsheet.
- Repeat the procedure for two, three, and then four traits. You may wish to devise a method of organizing your different genetic combinations.

(a) What did you notice about the number of possible combinations as the number of traits increased?
(b) Humans possess genes for over 30 000 different genetic traits. With the exception of identical twins, is it surprising that no two siblings are alike? Explain.

INVESTIGATION 5.2 *Introduction*

Measuring Inherited Variation

In this investigation, you will design and conduct experiments to quantify inherited variations in living populations of a very successful species, *Homo sapiens*. You will then design and carry out your own investigation into the amount of variation in an inherited trait of a species of your choice.

To perform this investigation, turn to page 164.

Report Checklist

○ Purpose	● Design	● Analysis
○ Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	● Synthesis
● Prediction	● Evidence	

SUMMARY *Sources of Inherited Variation*

- Inherited variations are determined by differences in genes between individuals.
- The study of genetics redefined evolution as a change in the genetic makeup of a population over time.
- Since genes recombine during sexual reproduction, this process contributes to individual variability in populations.
- Mutations are the only source of new genetic material. Mutations may be neutral, harmful, or beneficial.
- Beneficial mutations may increase the fitness and reproductive success of an individual and therefore may become more common in a population. Harmful mutations decrease fitness and reproductive success and do not tend to accumulate.

Section 5.5 Questions

1. What key information regarding variation was missing in Darwin's explanation of the evolution of species?
2. Compare and contrast the contributions of sexual reproduction and mutation in producing variation within populations. Consider both short- and long-term influences.
3. Following their initial contact with non-indigenous people, many populations of indigenous peoples suffered devastating losses from previously unknown diseases. How might evolutionary biology account for their low resistance to these diseases?
4. Examine the collection of sea urchins in **Figure 3**. Prepare a design statement for an investigation to compare the inherited variation in these species.

Extension

5. Research Richard Dawkins's theory about "selfish genes." Prepare arguments and counter-arguments for a class debate on his theory.

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Figure 3
Sea urchin exoskeletons

Speciation and Evolution 5.6

Natural selection provides an explanation of how species become better adapted to their environment. Does it also account for the formation of new species (**speciation**) and, from there, entire new groups of living organisms? A species can be thought of as a population of individuals who are reproductively isolated—they are not capable of breeding with individuals of other species under natural conditions. Most new species are believed to arise by a three-step process called **allopatric speciation**.

1. A physical barrier separates a single interbreeding population into two or more groups that are isolated from each other. Any mutations that occur in one of these isolated groups are not shared with the other population(s) (**Figure 1**).
2. Natural selection works on the separated groups independently, resulting in inherited differences in the two populations. In other words, the populations evolve independently. Differences in selective pressures will be greater if the populations experience pronounced differences in their environments.
3. In time, accumulated physical and/or behavioural differences between the populations become so pronounced that the groups, should they be reunited, would no longer be sexually compatible. At this point, they have formed two or more distinct species (**Figure 2**).

Physical barriers range in size from entire mountain ranges and oceans to river channels and canyons. On a smaller scale, human constructions such as dams and canals may produce insurmountable physical barriers to small organisms.

Speciation can also occur when a single population splits into distinct breeding populations when occupying a single geographic region (**Figure 3**). This process can be sudden. One form occurs when a mutation results in individuals with double or more the normal number of chromosomes. These individuals may be healthy and vigorous but reproductively isolated from the rest of the population. They are only able to mate with other similar polyploids. Many plant species are thought to have evolved by this mechanism.



Figure 3
Genetic evidence strongly suggests that a number of different species of sticklebacks living in some lakes in British Columbia evolved as a result of mutations that produced sudden changes in chromosome numbers.

speciation the formation of new species

allopatric speciation speciation by reproductive isolation





Figure 1
Wood bison **(a)** and plains bison **(b)** are reproductively isolated. Wood bison live in northern wooded areas in Canada, while plains bison live on the Prairies in both Canada and the United States.



Figure 2
This black-and-white lemur of Madagascar island is an example of allopatric speciation. Separated from the continent of Africa for over 1 million years, Madagascar now hosts some 8000 plant species and 1200 animal species found nowhere else.

WEB Activity

Case Study—Lactose Intolerance and Evolution

Lactose intolerance is the inability to digest lactose (milk sugar). Interestingly, certain groups of people, including First Nations people and those of African descent, are more likely to suffer from this condition. How does the theory of evolution account for these findings? Can we make and test predictions regarding the evolution of this condition? Working in a small group, investigate these questions by completing this Web Activity.

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The Rate of Evolution

theory of gradualism the idea that speciation takes place slowly

theory of punctuated equilibrium the idea that species evolve rapidly, followed by a period of little or no change

Until the mid-20th century, most biologists thought that changes to species occurred at a slow, steady pace. By this **theory of gradualism**, we would expect to find many fossils that showed small changes in species over time. Instead, distinct species often appear abruptly in the fossil record, and then little further change is seen over very long periods of time. In 1972, Niles Eldridge of the American Museum of Natural History and Stephen Jay Gould of Harvard University proposed **the theory of punctuated equilibrium** to account for these patterns in the fossil record. This theory has three main assertions:

- many species evolve very rapidly in evolutionary time
- speciation usually occurs in small isolated populations, so intermediate fossils are very rare
- after an initial burst of evolution, species are well adapted to their environment and so do not change significantly over long periods of time

These contrasting theories about the rate of evolution are shown in **Figure 4**. To some extent, the differences between them are a matter of perspective. To paleontologists, a sudden or "rapid" change might mean the appearance of a new species in the fossil record within 100 000 years. In fact, both theories are needed to understand the fossil record while remaining compatible with many other forms of evidence.

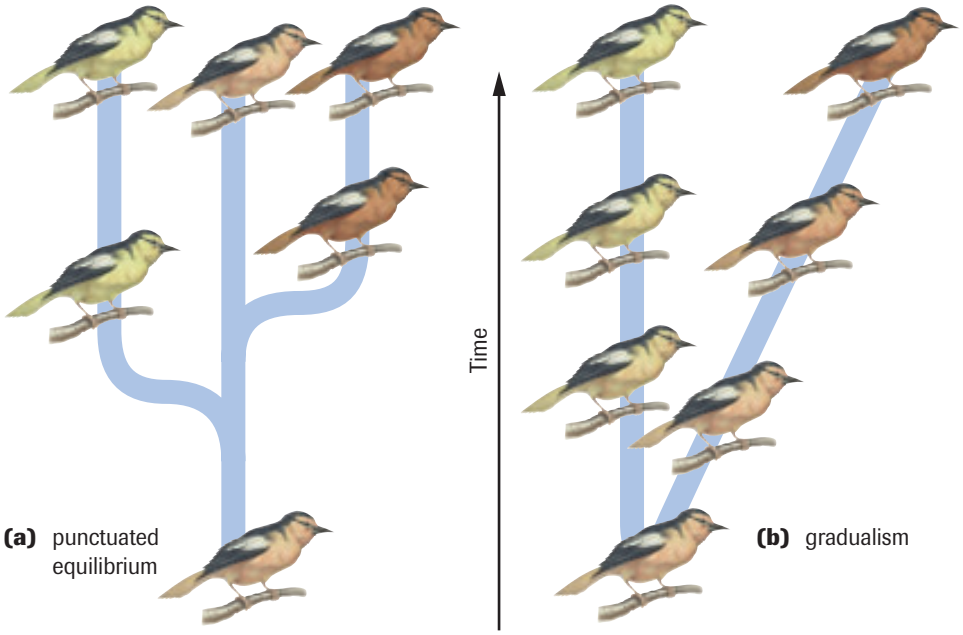


Figure 4
Two theories of the rate of evolution

Macroevolution: Diversification and Extinction

Figure 5, on the next page, shows the geological time scale and summarizes significant events in Earth's evolutionary history. Since life began, Earth has experienced an increase in diversity of living things. However, this trend has been interrupted by several major "extinction events," each identified by a thick red line in **Figure 5**. The Paleozoic era, for example, began with a rapid increase in the number of species, referred to as the Cambrian explosion, and ended 245 mya (million years ago) with the dramatic Permian extinction.

There is extensive fossil evidence for the Cambrian explosion. One of the most important fossil discoveries in the world, the Burgess Shale in Canada's Rocky Mountains, contains beautifully preserved 515-million-year-old fossils of marine life. The great diversity—more than 120 species—is evidence of **divergent evolution**, when species rapidly evolved into many different species during the early Cambrian period.

divergent evolution evolution into many different species

At the end of the Paleozoic era, between 240 and 225 mya, a series of cataclysmic events eradicated more than 90 % of the known marine species. The causes of this Permian extinction are unknown, but many scientists suspect tectonic movements. The Mesozoic era, well known for its dinosaurs, also came to a sudden end about 65 mya, when the remaining dinosaurs and many other species suddenly disappear from the fossil record. Considerable evidence supports the hypothesis that an asteroid impact caused this best-known mass extinction. The Chicxulub Crater, almost 10 km deep and 200 km in diameter at the edge of the Yucatán Peninsula (**Figure 6**), is thought to have been the impact site. The debris and energy released in the resulting fireball—equivalent to 100 million nuclear bombs—would have killed most of the plants and animals in North and South America within minutes. Tsunamis 120 m high would have devastated coastlines around the world, and atmospheric debris would have blocked out much of the sunlight for months or even years.

While the mass extinctions that ended the Permian and the Mesozoic eras are dramatic, it is important to keep in mind that most extinctions of species result from the ongoing evolutionary forces of competition and environmental change. This "background" rate of extinction is slow—the average species exists for about a million years.



Figure 6
A computer-generated image of the moment of impact that created the 200-km-wide Chicxulub Crater, in the ocean floor at the edge of the Yucatán Peninsula.

Putting the Theory of Evolution to Work: Predictions

All scientific theories are judged on their ability to (1) account for old and new evidence and (2) make testable predictions. How does the theory of evolution stand up to this judgement? As you have learned, the theory of evolution is clearly able to account for a wide range of evidence, but can it be used to make testable predictions?

Because evolution is usually a very slow process, it is difficult to witness evolutionary change directly, making it difficult to test predictions about the future evolution of a species. Predicting future *events,* however, provides an equally rigorous method of testing a theory. The following example illustrates such a test.

Prediction: Because they are not mobile, plants will have evolved toxic and bitter-tasting compounds to deter predators. These compounds are likely to be concentrated in their delicate leaves.

Evidence: Most plant tissues, and particularly leaf tissues, are far more toxic than animal tissues.

EXTENSION

Measuring Time
This video discusses evidence of changes in Earth's history resulting from the asteroid that hit the Yucatán Peninsula.

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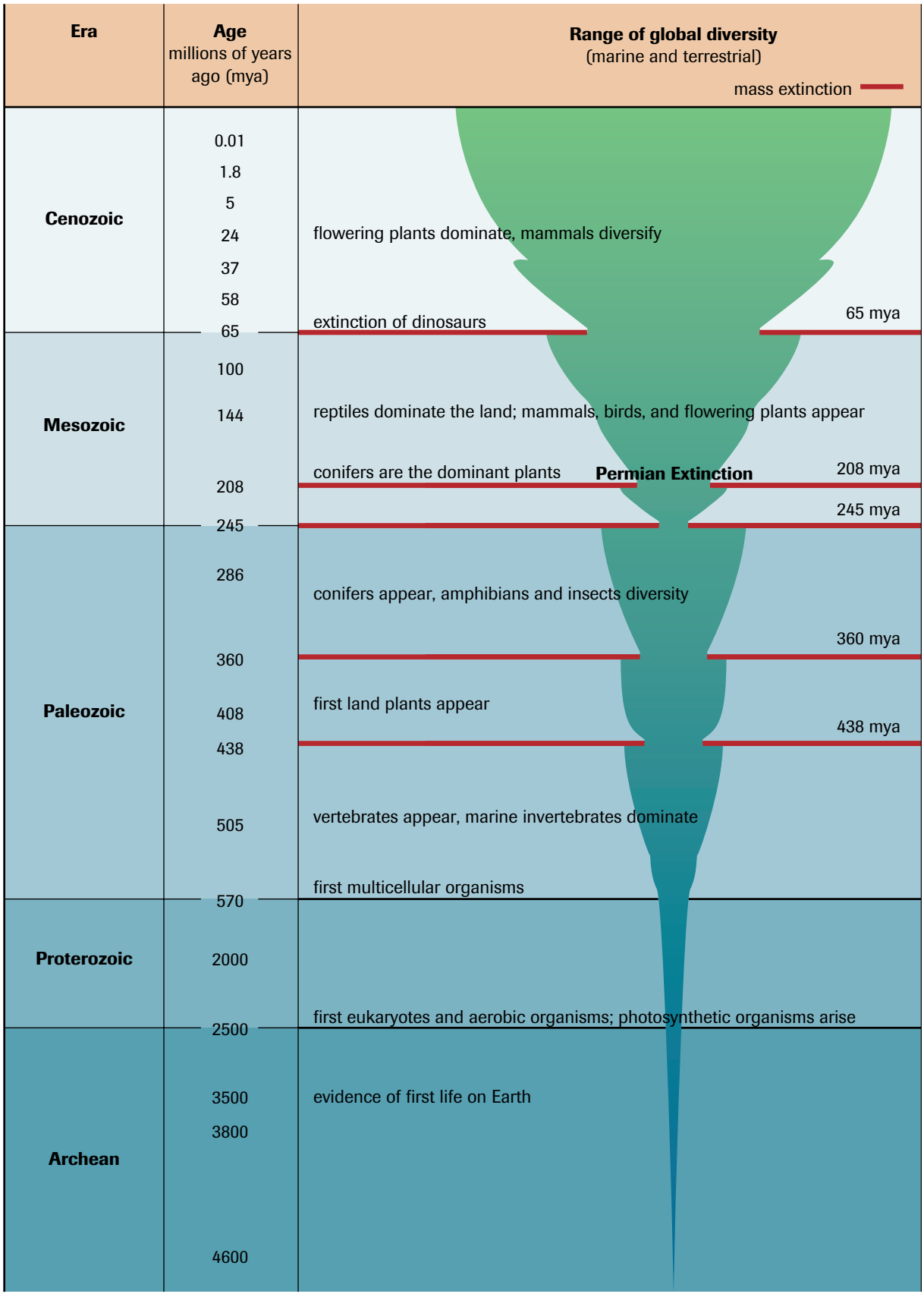


Figure 5
Major events of life on Earth

WEB Activity

Simulation—Natural Selection

The reproductive success of the peppered moth has been observed to be related to its colouring. In this online investigation, you will observe the effects of a change in the colour of environment on a population of virtual creatures of variable coloration. Will the simulation model the real-life observations with peppered moths?

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SUMMARY Speciation and Evolution

- New species have evolved when two or more populations become reproductively isolated from each other.
- Geographic isolation may be the most common cause of populations evolving into separate species (allopatry).
- The pace, or rate, of evolution is variable—the theories of gradualism and punctuated equilibrium account for various patterns seen in the fossil record.
- Earth has experienced periods of rapid diversification of living things—divergent evolution—as well as episodes of mass extinction.

Section 5.6 Questions

1. Outline the steps involved in allopatric speciation.
2. Living in the same region, the almost identical species of tree frog, *Hyla veriscolor* (**Figure 7 (a)**) and *Hyla chrysoscelis* (**Figure 7 (b)**) are distinguished only by their vocal calls and their DNA. *H. veriscolor* has exactly twice the number of chromosomes as *H. chrysoscelis.* How might *H. versicolor* have evolved?



(a) **(b)**

Figure 7

3. Construction of a canal through Panama has affected marine and terrestrial species. Consult an atlas to see the extent of the canal.
   (a) Comment on effects on the evolution and speciation of Atlantic and Pacific marine organisms in the vicinity of the Panama Canal.
   (b) How might the construction of the Panama Canal have influenced the evolution of terrestrial species?
4. What aspect of the fossil record suggests that evolution may occur rapidly?
5. Compare and contrast the theories of punctuated equilibrium and gradualism.
6. Evolutionists have concluded that mammals evolved from a group of reptiles. Based on your understanding of fossil formation and evolution, make a testable prediction about the fossil records of mammals and reptiles. Conduct literature and Internet research to see if your prediction was valid.

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INVESTIGATION 5.1

Using a Classification Key

Whales are often grouped as either toothed or baleen whales. Baleen whales have a series of vertical plates that branch and crisscross at the opening of the mouth. Each plate acts as a filter, straining small marine life from the seawater.

Report Checklist

● Purpose	● Design	● Analysis
● Problem	○ Materials	○ Evaluation
○ Hypothesis	● Procedure	● Synthesis
● Prediction	● Evidence	

Purpose

To identify various species of whales using a dichotomous key

Procedure

1. Use **Figure 1** to help you identify the whale's body structures referred to in the key.

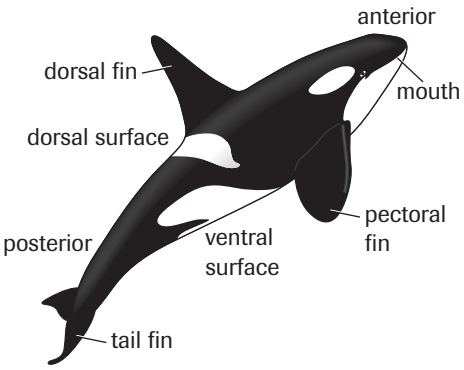


Figure 1

2. To identify each whale in **Figures 2** to **8**, start by reading part 1(a) and (b) of The Key (below). Then follow the "Go to" direction at the end of the appropriate sentence until the whale has been properly classified.

Analysis

(a) What are four characteristics used to classify whales?

(b) Why might biologists use a key?

(c) Provide an example of when a biologist might use a key to classify whales.

(d) Make a list of other characteristics that could be used to classify whales.

Evaluation and Synthesis

(e) Research to find out more about whales, for example, their distribution ranges and whether a species is threatened or endangered.

(f) Identify eight different trees or shrubs native to your locale and make a dichotomous key that allows others to identify them.

The Key	
1. (a) baleen plates (b) teeth	Go to 2. Go to 4.
2. (a) dorsal fin (b) no dorsal fin	Go to 3. bowhead whale (*Balaena mysticetus*)
3. (a) long pectoral fin (b) short pectoral fin	humpback whale (*Megaptera novaeangline*) blue whale (*Balaenoptera musculus*)
4. (a) no dorsal fin (b) large dorsal fin	Go to 5. killer whale (*Orincus orca*)
5. (a) small nose (b) large projection from nose	Go to 6. narwhal (*Mondon monoceros*)
6. (a) mouth on ventral surface (underside) of head (b) mouth at the front of head	sperm whale (*Physeter macrocephalus*) beluga (*Delphinapterus leucas*)

INVESTIGATION 5.1 *continued*



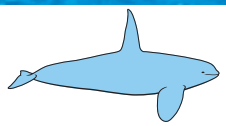


Figure 2
- teeth
- adult length: 6.0 m (females), 6.7 m (males)
- adult mass: 7.4 tonnes (t) (females), 10.5 t (males)



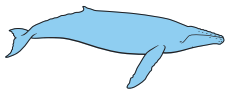
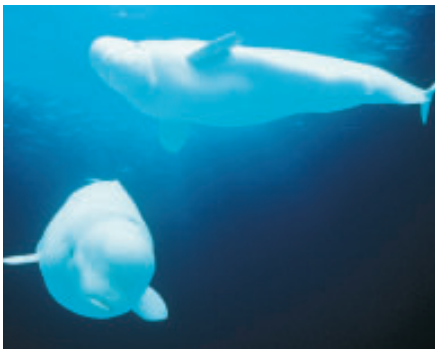


Figure 3
- baleen plates
- adult length: 13.7 m (females), 12.9 m (males)
- adult mass: 25 t–30 t



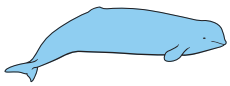


Figure 4
- teeth
- adult length: 3.5 m (females), 4.5 m (males)
- adult mass: 1.0 t (females), 1.2 t (males)



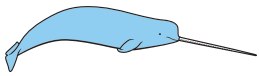


Figure 5
- teeth
- adult length: 4.2 m (females), 4.7 m (males)
- adult mass: 900 kg (females), 1.6 t (males)



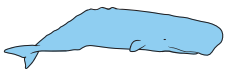


Figure 6
- teeth
- adult length: 11 m (females), 15 m (males)
- adult mass: 20 t (females), 45 t (males)



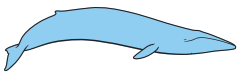
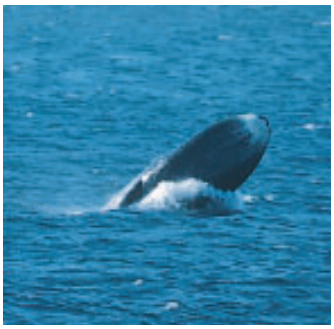


Figure 7
- baleen plates
- adult length: 26.5 m (females), 25 m (males)
- adult mass: 200 t (females), 100 t (males)



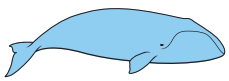


Figure 8
- baleen plates
- adult length: 14 m–15 m
- adult mass: 50 t–60 t

INVESTIGATION 5.2

Measuring Inherited Variation

Report Checklist

○ Purpose	● Design	● Analysis
○ Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	● Synthesis
● Prediction	● Evidence	

If, as Darwin asserted, natural selection is occurring throughout the living world, then all species of organisms must possess inherited variations. In this investigation, you will design and conduct experiments to quantify inherited variations in living populations.

Part 1: Human Variability

Humans are the only exclusively bipedal mammals—that is, we walk upright on two feet. This characteristic is clearly inherited. In this investigation, you will quantify variation in the length of the human foot and investigate whether such variation is inherited. Before beginning your investigation, generate one or more testable hypotheses regarding both variability and inheritability of human foot length.

Design Suggestions

1. Devise a method to accurately measure human foot length.
2. Consider using commercial shoe sizes for your data. How might this influence the accuracy and objectivity of the data? Would this be offset by the ability to obtain more data?
3. Gather and tabulate inheritance evidence as a set of ordered pairs. Each data set should include foot length of an offspring paired with the foot length of the biological parent of the same gender (boys with their father, girls with their mother).
4. Take into account the influence of student age in your investigation.
5. Use histograms to display sample variation and (*x*,*y*) coordinate graphs to display inheritability. **Figure 1** shows an example of each.

Analysis

(a) Comment on the degree of variation you observed in human foot length. Describe any patterns in the data.

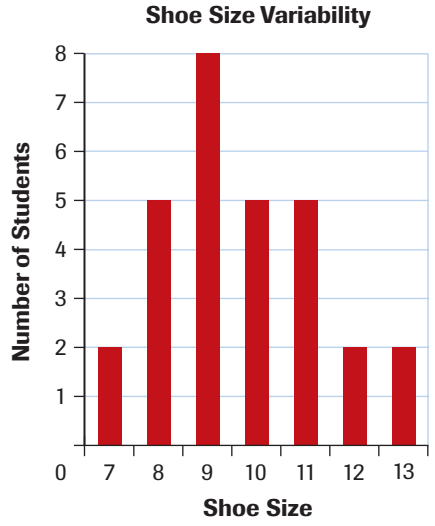
(b) Did the range of male foot length differ from that in females?

(c) What was the mean foot length among the males and the females you studied?

(d) Were some foot lengths obviously more common? Were the more common foot length(s) closer to the mean of foot length or to one of the extremes?

(e) Describe any evidence you found that foot length is an inherited trait.

(a)



(b)

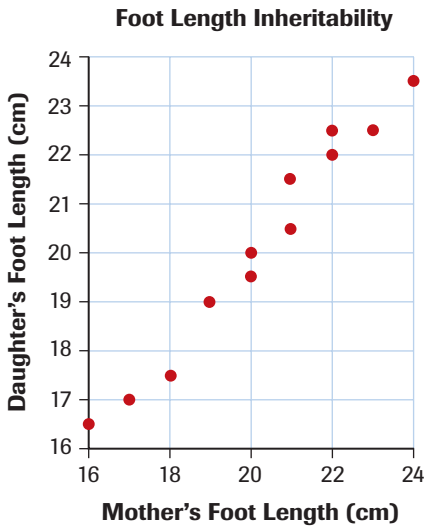


Figure 1
(a) histogram of number of male students versus shoe size
(b) daughter's foot length (cm) (*y*-axis) versus mother's foot length (cm) (*x*-axis)

INVESTIGATION 5.2 *continued*

(f) Does the evidence suggest that foot length is an inherited trait that remains unchanged between a child and the parent of the same gender? Explain.

Evaluation

(g) Do the sample data in **Figure 1 (b)** appear realistic? Do you think they represent actual data? Explain.

(h) How might the age of the offspring have influenced the results of your investigation?

(i) Do you think the age of the parents influenced your results? Why?

(j) What could you do differently to eliminate or reduce the influence of offspring age?

(k) How could you modify the experimental design to determine whether both parents influence foot length?

Synthesis

(l) Foot length was chosen for this investigation because it was suspected of being an inherited trait, at least in part. What environmental factors could be partly responsible for human foot length?

(m) What physical human characteristics are variable but are not inherited?

(n) What role might sexual reproduction have played in influencing the variability and inheritability of foot length in this investigation?

Part 2: Variations in Nature

Design and conduct an investigation similar to Part 1, using a quantifiable characteristic of an animal or plant species. For example, you might investigate the number of seeds per fruit or seed germination time; or adult height of cats or dogs. Select a characteristic that you know or can assume is inherited. The evidence you collect must either support or refute the following hypothesis: All species exhibit variations in inherited traits.

Analysis

(o) Based on the findings of your investigation, as well as the investigations of your classmates, what general conclusions can you draw about the variability within species?

Evaluation

(p) What role does the variability of a trait have in influencing its evolution? Is variation necessary for evolution? Explain.

(q) How might the length or size of the following anatomical structures have proven advantageous for these animals?

(i) neck of a swan

(ii) an elephant's trunk

(iii) moose or elk antlers

(iv) long legs of herons

(v) rattlesnake fangs

Synthesis

(r) The results of a scientific study often lead to new questions which become the topic of future investigations. Generate three new questions that arise from your findings that could be the basis of additional investigations.

Chapter 5 SUMMARY

Outcomes

Knowledge

- explain the fundamental principles of taxonomy, i.e., domains, kingdoms, and binomial nomenclature (5.1)
- explain that variability in a species results from heritable mutations and that some mutations may have selective advantage(s), i.e., fossil record, Earth's history, embryology, biogeography, homologous and analogous structures, and biochemistry (5.5)
- discuss the significance of sexual reproduction to individual variation in populations and to the process of evolution (5.5)
- compare Lamarckian and Darwinian explanations of evolutionary change (5.4)
- summarize and describe lines of evidence to support the evolution of modern species from ancestral forms (5.2, 5.3, 5.6)
- explain speciation and the conditions required for this process (5.6)
- describe modern evolutionary theories, i.e., punctuated equilibrium versus gradualism (5.6)

STS

- explain that conventions of mathematics, nomenclature, and notation provide a basis for organizing and communicating scientific theory, relationships, and concepts (5.1)
- explain that scientific knowledge and theories develop through hypotheses, the collection of evidence, observation, and the ability to provide explanations (5.2, 5.3, 5.6)

Skills

- ask questions about observed relationships and plan investigations by designing an investigation to measure or describe an inherited variation in a plant or animal population (5.5); and hypothesizing the adaptive significance of the variations in a range of homologous structures in extant and extinct organisms (5.2, 5.3)
- conduct investigations and use a broad range of tools and techniques (all)
- analyze data and apply mathematical and conceptual models by: applying classification and binomial nomenclature systems in a field study (5.1), and analyzing data, actual or simulated, on plants and animals to demonstrate how morphology changes over time (5.3, 5.4, 5.5, 5.6)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

5.1

taxonomy
binomial nomenclature
genus
species
taxon (pl. taxa)
Protista
Monera
Archaebacteria
Eubacteria
phylogeny
dichotomous key

5.2

paleontology
radiometric dating
biogeography
endemic

5.3

homologous features
analogous features
vestigial features
DNA
gene
artificial selection

5.4

spontaneous generation
inheritance of acquired characteristics
natural selection

5.5

mutation
neutral mutation
fitness
harmful mutation
beneficial mutation
asexual reproduction
siblings
sexual reproduction
gene pool

5.6

speciation
allopatric speciation
theory of gradualism
theory of punctuated equilibrium
divergent evolution

MAKE a summary

1. Our current understanding of the evolution of life on Earth was gained using methods of scientific inquiry. We have used these methods to gather evidence and understand both the processes and the products of evolution. Design and construct a concept map that depicts these key elements. Your concept map should make creative use of information and communication technologies. You might construct a Web page concept map with hyperlinks to Web sites, information, or image files. Alternatively, you may want to make use of digital technology.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To

www.science.nelson.com GO

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 5
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

EXTENSION

Little People of Flores

The remains of three-foot-tall humans are discovered on a remote Indonesian Island. How have scientists interpreted these skeletons? This is a *NOVA* video.

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EXTENSION

CBC radioONE QUIRKS & QUARKS

Newts and Garter Snakes

Dr. Butch Brodie, (professor of biology at Indiana University) describes natural selection and the amazing predator-prey interactions of the toxic rough-skinned newt and the garter snake. A genetic mutation allows the snake to eat this highly poisonous prey. The newt's toxin is so strong it can quickly kill humans, yet the snake has managed to adapt to the toxin.

www.science.nelson.com GO

EXTENSION

T. rex

An astonishing adolescent growth spurt accounts for T. rex's enormous size. Scientists were able to make conclusions about the life span of this huge dinosaur by comparing fossilized bones to homologous bones in modern alligators. This is a *NOVA* video.

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UNIT 20 B PERFORMANCE TASK

The Sixth Extinction

In this Performance Task, you will use the knowledge and skills you have gained in this unit to compare past and current extinctions. Go to the Unit 20 B Performance Task link on the Nelson Web site and complete the task.

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Chapter 5 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. Radiometric dating provided scientists with
   A. a method for determining the exact age of sedimentary deposits
   B. a method for determining the age of a fossil by measuring its radioactivity
   C. a method of dating that is not accurate for objects only a few thousand years old
   D. a method for accurately dating igneous rock and for estimating the age of Earth

2. The theory of evolution by acquired characteristics did not include which of the following ideas:
   A. strenuous activities can change organisms
   B. organisms can change during their own lifetime
   C. physical characteristics cannot be passed to offspring
   D. the environment plays a role in selecting favourable characteristics

3. Jean-Baptiste Lamarck is important to the study of evolution because he
   A. conducted genetic experiments with garden peas
   B. proposed a theory of evolution called adaptations
   C. proposed a theory of evolution called natural selection
   D. proposed that the environment could drive evolutionary change

Use the following information to answer questions 4 to 6.

Darwin's voyage allowed him to observe species with distinct inherited variations. Based on the work of Malthus, Darwin realized that all populations produce far more offspring than can survive long enough to reproduce. From this, Darwin developed the concept of natural selection.

4. Malthus's work was important to Darwin's theory of evolution because it led him to conclude that
   A. all species show inherited variation
   B. there is competition among individuals of the same species
   C. all populations can be expected to increase in size over time
   D. the individuals with the best traits will be more likely to survive and reproduce

5. Since he found inherited variations in all species, Darwin concluded that
   A. variations between individuals were random
   B. the environment did not influence the characteristics of individuals
   C. variation did not play a significant role in the mechanism of evolution
   D. some individuals might be better suited to the environment than others

6. According to Darwin's theory of natural selection, a struggle for survival is a result of
   A. the occurrence of mutations
   B. many species competing with one another
   C. the variation of traits among individuals of a species
   D. the large number of offspring born in each generation

7. A species of flying squirrel inhabited an island. Ten thousand years ago, ashes from a nearby volcano killed most of the vegetation, including all the trees. A few flying squirrels survived. Today, squirrels are abundant, living among the rocks and shrubs that now cover the island. In the present population, the "flight membranes" are mostly too small to be functional. The most probable explanation for this change is that
   A. all the squirrels that could fly left the island
   B. a new type of squirrel was introduced to the island
   C. natural selection no longer favoured those that could fly
   D. young squirrels were not taught to fly by their parents, so the membranes did not develop

8. NR Many poisonous frogs are brightly coloured (**Figure 1**). This adaptation is thought to protect the frog by warning off potential predators. Assume that each of the following steps occurred in the evolution of the warning coloration. Place them in chronological order from the earliest to the most recent. (Record all four digits of your answer.)
   1. Predators associated the foul-tasting frogs with their coloration and stopped feeding on them.
   2. Some frogs within the population had mutations that made them more brightly coloured.
   3. Some frogs within the population had mutations that made them toxic to some predators.
   4. These frogs were more likely to survive than others, and this trait became established among all the frogs of this species.



Figure 1

9. Examine and compare the following samples of DNA. Using this evidence, place species 1, 2, 3, and 4 in order from *most* closely related to *least* closely related to species X.

species X AATCCGAGGTATAGCTACCAGAATCCGGG

A. species 1 AATCGGAGGTATAGCTACCAGAATCCGGG

B. species 2 AATCCGAGCTATAGCCACCAGAATCCAGG

C. species 3 ATTTCTAGGTATAGGGACCAGCATCCTGG

D. species 4 AATCCGAGGTATAGCTACCAGAATCCCGG

10. NR Each of the following individuals had ideas about the evolution of life on Earth. Place their names in chronological order from the earliest to the most recent. (Record all four digits of your answer.)

1. Buffon
2. Darwin
3. Wallace
4. Lamarck

Part 2

11. When Europeans arrived in Hawaii, they introduced rats, cats, dogs, and other predators. As a direct consequence, 61 of Hawaii's 96 species of native birds have already gone extinct. **Relate** this set of events to the theory of evolution by describing how natural selection influenced Hawaii's bird species before and after the arrival of Europeans.

Use the following information to answer questions 12 to 16.

The computer simulation entitled "Methinks It Is Like a Weasel" uses the analogy of a monkey typing randomly at a keyboard to compare pure chance with natural selection. After reading the online introduction and background information, run the simulation several times, noting both the ongoing processes and the end results.

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12. DE **Describe** what in the natural environment is being modelled by the phrase "Methinks it is like a weasel".

13. DE **Identify** the process that leads to changes in the alleles of both the monkey at the keyboard and cumulative selection.

14. DE **Why** don't the beneficial mutations that arise in the monkey at the keyboard accumulate?

15. DE **Describe** what happens to harmful changes in the cumulative selection simulation.

16. DE Could the monkey at the keyboard actually generate the phrase "Methinks it is like a weasel?" **Explain**.

17. It is thought that a billion prairie dogs once populated an area of over 100 million ha. Their current territory has been reduced and fragmented to less than 1 % of this original space. **Predict** the impacts from these changes in habitat on the prairie dog gene pool, as well as on the evolution and survival of the species.

Use the following information to answer questions 18 to 21.

A fascinating evolutionary relationship exists between the genetic disorder sickle cell anemia and the infectious disease malaria. View the online video that describes this relationship and answer the questions.

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18. DE **Conclude** whether sickle cell anemia is a serious disorder.

19. DE **Conclude** whether malaria is a serious disorder.

20. DE **Conclude** whether it is always a disadvantage to have the sickle cell trait.

21. DE **Describe** how your geographic location influences whether the mutation that causes sickle cell anemia is harmful or beneficial.

Use the following information to answer questions 22 to 24.

Recent genetic analysis of purebred dogs, published in the journal *Science,* suggests that dog breeds can be distinguished with great accuracy by comparing their DNA. According to research scientist Elaine Ostrander, "At a DNA level, breeds are a very real concept. Every poodle is more closely related to a poodle than it is to a dog of any other breed."

22. DE **Describe** how this evidence supports the assertion that selection can lead to changes in the genetic makeup of a population.

23. DE **Describe** what this evidence suggests about the use of DNA analysis as a tool for evolutionary biologists.

24. DE **Describe** some possible advantages and disadvantages to comparing breeds or species based on their DNA as opposed to their physical or behavioural characteristics.

25. Some prions (infectious proteins) that cause diseases such as bovine spongiform encephalopathy (mad cow disease) and the inherited form of human spongiform encephalopathy (Creudtzfeldt-Jacob disease) result from single genetic mutations. Research the genetics of these diseases. **Explain** how they are transmitted and **why** they are not eliminated by natural selection.

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Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. All of the deer in a forest area of 100 km^2 can be described as a
   A. deer community
   B. deer population
   C. deer biome
   D. deer species

2. The cougar, African lion, and common house cat are all types of cats. They share all of the same taxonomic categories except
   A. family
   B. class
   C. genus
   D. order

3. In which taxonomic group do the members have the greatest number of similarities?
   A. kingdom
   B. family
   C. genus
   D. phylum

4. A niche is best described as
   A. biological components of an ecosystem
   B. abiotic factors of an ecosystem
   C. a population of a species of animals that occupies an area
   D. roles and interactions of a species within its community

5. A community includes
   A. the physical area where an organism lives
   B. all members of a certain species in a defined area
   C. the populations of all organisms that occupy a defined area
   D. all organisms in a population regardless of area

6. The addition of nutrients to a stream will immediately cause
   A. bacteria to increase, which will increase the level of dissolved oxygen in the stream
   B. bacteria to increase, which will decrease the level of dissolved oxygen in the stream
   C. bacteria to decrease, which will increase the level of dissolved oxygen in the stream
   D. bacteria to decrease, which will decrease the level of dissolved oxygen in the stream

7. Data were collected from three different sites along the North Saskatchewan River, and used to draw the graph in **Figure 1**. If a biologist took water samples from the river and measured the dissolved oxygen levels, she would find that dissolved oxygen is lowest at point
   A. W
   B. X
   C. Y
   D. Z

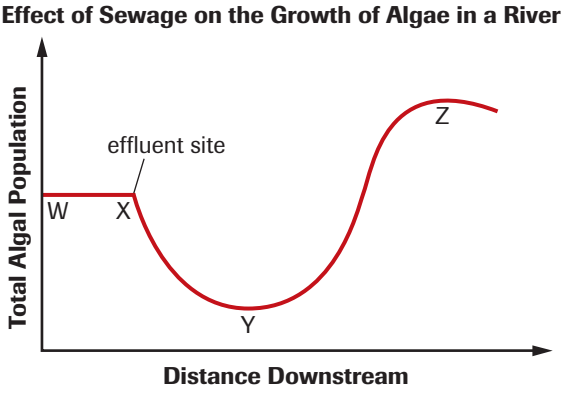


Figure 1

8. Which of the following statements is false?
   A. The littoral zone of a lake is farthest from the shore.
   B. The limnetic zone has more light than the profundal zone.
   C. The littoral zone is closer to the surface than the profundal zone.
   D. Aquatic plants do not usually grow in the profundal zone.

Use the following information to answer questions 9 to11.

Ecologists measured the amount of melted snow entering a river from April 1 to May 15. They also recorded the pH of the river. Their results are presented in **Figure 2**.

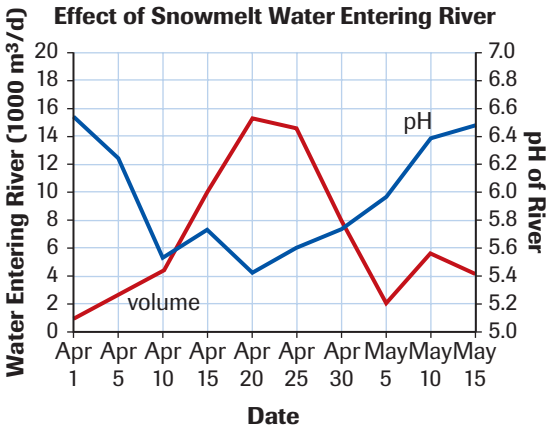


Figure 2

9. According to the data collected from the graph, as the snowmelt increases,
- A. the volume of water in the river increases and the pH becomes more acidic.
- B. the volume of water in the river decreases and the pH becomes more acidic.
- C. the volume of water in the river increases and the pH becomes more basic.
- D. the volume of water in the river decreases and the pH becomes more basic.

10. On which date was the water most acidic?
- A. April 1
- B. April 15
- C. April 20
- D. May 10

11. Which factor could account for the drop in pH during mid-April?
- A. increased photosynthesis during mid-April
- B. acid deposition enters the river with melting snow
- C. alkaline (basic) minerals in the soil are carried into the river with melting snow
- D. the increased volume of water entering the river dilutes the concentration of acids found in the river

---

12. Which of the following is not an acquired trait?
- A. the ability to read
- B. a suntan
- C. a tattoo
- D. sense of smell

13. NR Through natural selection, individuals with adaptations that increase their chances of survival will produce more offspring. As a result, those adaptations will become more common in the species over time and the species evolves. Sometimes, new adaptations in one species affect the evolution of an adaptation in another species. Consider the following pairs of adaptations. For each of the four pairs, record the number of the adaptation that is most likely to have evolved first. (Record all four digits of your answer from lowest-to-highest numerical order.)
1. insect-pollinated flowers OR 2. sacks on the legs of honeybees that hold pollen
3. the flying ability of insects OR 4. spider webs
5. a brightly coloured butterfly species OR 6. the same species is poisonous
7. certain mammals have forepaws that can grasp things OR 8. certain mammals begin living in trees

14. NR Place the following discoveries/theories in chronological order from earliest to most recent. (Record all four digits of your answer.)
1. Wallace develops a theory of evolution by natural selection.
2. First fossils are discovered.
3. Darwin goes on a voyage on HMS *Beagle*.
4. Lamarck hypothesizes the evolution of acquired characteristics.

Part 2

Use the following information to answer questions 15 to 18.

In an attempt to increase the local food supply for people, humans introduced 26 caribou (24 females and 2 males) to an island off the coast of Alaska in 1910. **Figure 3** shows how the reindeer population changed after the introduction.

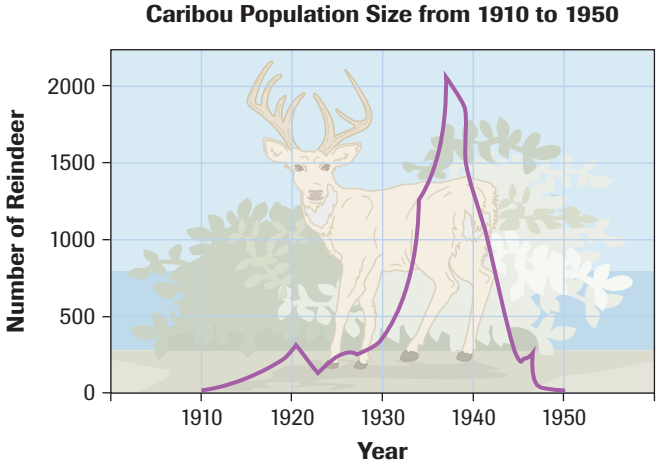


Figure 3

15. DE **Why** were more females introduced than male?

16. DE By 1937, the caribou population had soared to 2000. **Describe** the evidence that supports the hypothesis that the carrying capacity for reindeer had been exceeded.

17. DE Caribou feed on slow-growing lichens and moss. Would you expect to find more food for caribou on the island in 1931, 1935, or 1950? **Explain** your answer.

18. DE The introduction of a new species can cause major changes in an ecosystem. Should the caribou have been put on the island? **Explain** your position.

Use the following information to answer questions 19 to 25.

Scientists examined the aging of a lake over time. **Table 1** shows the data they collected from historical records. **Table 2**, on the next page, gives standard data on the change in solubility of carbon dioxide and oxygen with temperature. The scientists also collected historical data on fish populations in the lake over the same time period (**Table 3**).

Table 1 Recorded Lake Depth and Temperature

Year	Water depth (m)	Surface temp. (°C)	Bottom temp. (°C)
1885	25	25	10
1955	20	29	20
2000	14	30	25

Table 2 Solubility of Carbon Dioxide and Oxygen

Temp. (°C)	CO_2 solubility (ppm)	O_2 solubility (ppm)
0	1.00	14.6
5	0.83	12.7
10	0.70	11.3
15	0.59	10.1
20	0.51	9.1
25	0.43	8.3
30	0.38	7.5

Table 3 Fish Populations over Time

Year	Population of trout (per km^3)	Population of perch (per km^3)	Population of catfish (per km^3)
1885	12	22	14
1955	7	23	15
2000	1	12	16

19. **Describe** what happened to the lake as it aged, according to the data in **Table 1**.

20. **Outline** in a list factors that might explain why the lake became shallower as it aged.

21. **Graphically** represent the solubility of oxygen from the data in **Table 2**.

22. From the data from **Table 2**, **predict** the long-term consequences of prolonged warming.

23. **Explain** why the levels of carbon dioxide in many Canadian lakes increase during winter.

24. **Explain** the changes in fish populations over time shown by the data in **Table 3**.

25. **Identify** two human activities that may have accelerated the aging of the lake. For each of the activities, **describe** the negative environmental consequences and **explain** how those consequences can be minimized.

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26. The removal of all trees from a forest is called clear-cutting. After cutting, different trees are separated and processed to make different products. Many of the products are sold to other countries, such as the United States. Write a unified response addressing the following aspects of clear-cutting.

- **Why** is clear-cutting promoted by many businesses?
- **Identify** some of the ecological problems associated with clear-cutting.
- **Identify** and **explain** the roles of industry, government, and individuals to prevent the negative impact of uncontrolled clear-cutting of forests.

27. The Gaia Hypothesis proposes that Earth is alive. It suggests that our planet functions as a single organism that maintains conditions necessary for its survival. Although not accepted by all scientists, this theory provides many useful lessons about the interaction of physical, chemical, geological, and biological processes on Earth. Write a unified response that addresses the following aspects of the Gaia Hypothesis.

- Based on your understanding of the biosphere, **outline** in a list, ways in which Earth is similar to an organism.
- **Describe** one way that the Gaia Hypothesis might change the way scientists think about ecosystems.

Use the following information to answer questions 28 to 35.

Levels of nutrients, algae, and light penetration were measured throughout the year in the limnetic zone of a northern Alberta lake, producing the patterns shown in **Figure 4**.

Seasonal Changes in a Lake

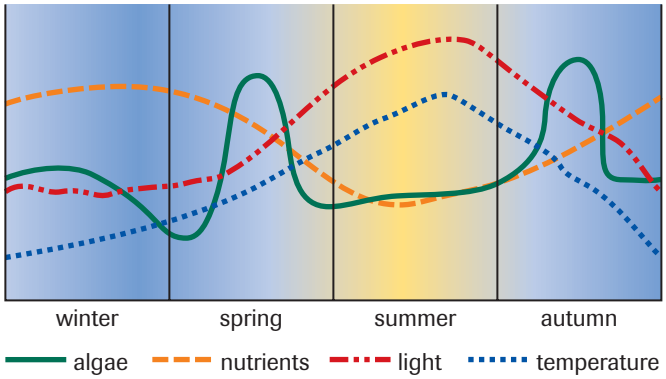


Figure 4

28. **Determine** from **Figure 4** at which times of the year the population of algae is highest.

29. **Explain** the changes in algae population.

30. **Explain** the changes in temperature.

31. **Why** do nutrient levels in the lake rise in winter but fall in summer?

32. **Explain** the fluctuations in light penetration.

33. Using **Figure 4** as a model, show **graphically** the changes you would expect to see in dissolved oxygen in the same lake.

34. Using **Figure 4** as a model, show **graphically** the changes you would expect to see in BOD in the same lake.

35. **Explain** how the patterns would change if sewage began to be dumped into the lake.

---

36. **Compare** (point out similarities and differences) how the theories of Lamarck and Darwin would explain each of the following:
(a) **how** the giraffe evolved a long neck
(b) **how** the cheetah became an extremely fast runner

37. Mutations are very rare events.
(a) **Explain** if you agree with the above statement, if it were referring to an individual organism.
(b) **How** would your answer differ if you were referring to mutation events in an entire population over long periods of time?
(c) Would your answer to part (b) differ if you were referring to an elephant population? to a bacterial population? **Explain**.

38. **Describe** a testable hypothesis for Lamarck's theory of inheritable acquired traits. **Describe** an experimental design that would test your hypothesis.

39. **Relate** the variability of a species to its mode of reproduction (i.e., asexual or sexual).

40. DE Darwin recognized that natural selection by the environment could produce change in a way similar to the artificial selection used by plant and animal breeders. Write a unified response that addresses the following aspects of these two processes.
- **Compare** the sources of new variation in each process. **Illustrate** your answer with an example.
- **Describe** any role of selection for certain characteristics in each process. **Illustrate** your answer with an example.
- **Describe** any role of selection against certain characteristics in each process. **Illustrate** your answer with an example.
- **Compare** the length of time needed before noticeable differences can be seen. **Illustrate** your answer with an example.

41. DE As a result of human activity, extensive forests are becoming fragmented into small forest islands. Write a unified response that addresses the following aspects of forest fragmentation:
- **How** might the increasing isolation of populations in these forests influence their success and evolution?
- **How** might the effects differ for a large mammal species, such as the lynx, compared to an insect species, such as a beetle?

42. Evolutionary biologists have hypothesized that many epidemics—widespread diseases that usually kill their hosts, such as smallpox or plague—could only have evolved in large human populations. Further, they hypothesize that these diseases originated in mammals that were domesticated. Consider these hypotheses in relation to contact between European explorers and indigenous peoples, such as the Arawak, Aztec, Maya, Inca, Aboriginal peoples in North America, Aborigines in Australia, and Maori in New Zealand. Research the exchange of diseases between Europeans and any two of the indigenous peoples listed above. Look for evidence that supports one or both of these hypotheses. **Describe** your findings in a presentation to your class.

Use the following information to answer questions 43 to 47.

A study by Environment Canada showed variations in the number of prairie ponds in the 30 years from 1955 to 1984 (**Figure 5**). Graph A shows the number of ponds found in each year of the study. Graph B shows the total population of ducks each year. Scientists conducting the study suggest that the decline was caused by draining ponds to expand agricultural land.

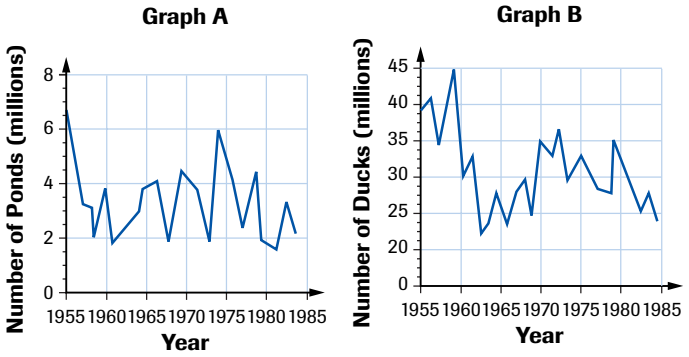


Figure 5

43. DE Farming is not the only cause of changes in the number of ponds. **Hypothesize** what abiotic factor might cause the number of ponds to fluctuate from year to year.

44. DE **Determine** the year in which the fewest number of ponds were found.

45. DE A hunters' group says that prairie ponds should be protected, to increase the number of ducks. Restate the hunters' position as a hypothesis, and **explain** whether the evidence in **Figure 5** support the hypothesis.

46. DE If the number of ducks declines, **predict** what other populations might be affected? **Explain** your answer.

47. DE Protecting ponds makes both aquatic and ecotone habitats available for wildlife but reduces the area of land on which a farmer can grow crops. Write a letter to a grain farmer, expressing your opinion about whether ponds on farmland should be protected or filled in. **Justify** your opinion.

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48. Review the focusing questions on page 80. Using the knowledge you have gained from this unit, briefly **outline** a response to each of these questions.